



FINAL REPORT OF THE SPACE SHUTTLE PAYLOAD PLANNING WORKING GROUPS

SOLAR PHYSICS

MAY 1973

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

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GLOSSARY

| <u>Abbreviation</u> | <u>Description</u> |
|---------------------|--|
| ATM | Apollo Telescope Mount |
| ESRO | European Space Research Organization |
| LSO | Large Solar Observatory |
| LTE | Local Thermodynamic Equilibrium |
| MHD | Magneto Hydrodynamic |
| NASA | National Aeronautics and Space Administration |
| NSSDC | National Space Science Data Center |
| OAQ | Orbiting Astronomical Observatory |
| OSO | Orbiting Solar Observatory |
| PASOL | Post Apollo Solar Astronomy Group |
| SPARCS | Solar Pointing Attitude Rocket Control System |
| VLA | Very Large Array (Interferometer) |
| XUV | Extreme Ultraviolet |

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FOREWORD*

In January 1972 the United States decided to develop a new space transportation system, based on a reusable space shuttle, to replace the present expendable system.

By January 1973 planning had progressed to the point that through the European Space Research Organization (ESRO) several European nations decided to develop a Space Laboratory consisting of a manned laboratory and a pallet for remotely operated experiments to be used with the shuttle transportation system when it becomes operational in 1980.

In order to better understand the requirements which the space transportation must meet in the 80's and beyond; to provide guidance for the design and development of the shuttle and the spacelab; and most importantly, to plan a space science and applications program for the 80's to exploit the potential of the shuttle and the spacelab, the United States and Europe have actively begun to plan their space programs for the period 1978-1985, the period of transition from the expendable system to the reusable system. This includes planning for all possible modes of shuttle utilization including launching automated spacecraft, servicing spacecraft, and serving as a base for observations. The latter is referred to as the sortie mode. The first step in sortie mode planning was the Space Shuttle Sortie Workshop for NASA scientists and technologists held at the Goddard Space Flight Center during the week of July 31 to August 4, 1972. For the purposes of that workshop, shuttle sortie missions were defined as including those shuttle missions which employ observations or operations (1) from the shuttle itself, (2) with subsatellites of the shuttle, or (3) with shuttle deployed automated spacecraft having unattended lifetimes of less than about half a year.

In general the workshop was directed towards the education of selected scientific and technical personnel within NASA on the basic capabilities of the shuttle sortie mode and the further definition of how the sortie mode of operation could benefit particular disciplines. The specific workshop objectives included:

- Informing potential NASA users of the present sortie mode characteristics and capabilities
- Informing shuttle developers of user desires and requirements
- An initial assessment of the potential role of the sortie mode in each of the several NASA discipline programs
- The identification of specific sortie missions with their characteristics and requirements

*Reprinted from the volume entitled "Executive Summaries".

- The identification of the policies and procedures which must be changed or instituted to fully exploit the potential of the sortie mode
- Determining the next series of steps required to plan and implement sortie mode missions.

To accomplish these objectives 15 discipline working groups were established. The individual groups covered essentially all the space sciences, applications, technologies, and life sciences. In order to encourage dialogue between the users and the developers attendance was limited to about 200 individuals. The proceedings were, however, promptly published and widely distributed. From these proceedings it is apparent that the workshop met its specific objectives. It also generated a spirit of cooperation and enthusiasm among the participants.

The next step was to broaden the membership of the working groups to include non-NASA users and to consider all modes of use of the shuttle. To implement both objectives the working group memberships were expanded in the fall of 1972. At this time some of the working groups were combined where there was appreciable overlap. This resulted in the establishment of the 10 discipline working groups given in Attachment A. In addition European scientists and official representatives of ESRO were added to the working groups. The specific objectives of these working groups were to:

- Review the findings of the GSFC workshop with the working groups
- Identify as far as possible the missions (by mode) that will be required to meet the discipline objectives for the period 1978 to 1985
- Identify any new requirements or any modifications to the requirements in the GSFC report for the shuttle and sortie systems
- Identify the systems and subsystems that must be developed to meet the discipline objectives and indicate their priority and/or the sequence in which they should be developed
- Identify any new supporting research and technology activity which needs to be initiated
- Identify any changes in existing procedures or any new policies or procedures which are required in order to exploit the full potential of the shuttle for science, exploration and applications, and provide the easiest and widest possible involvement of competent scientists in space science
- Prepare cost estimates, development schedules and priority ranking for initial two or three missions

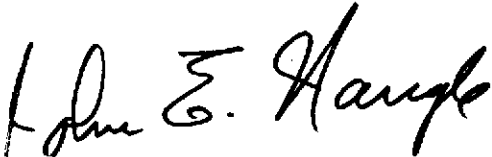
In order to keep this planning activity in phase with the shuttle system planning the initial reports from these groups were scheduled to be made available by the spring of 1973. It was also felt necessary that the individual working group activities be coordinated both between the groups and with the shuttle system planning. As a result, the steering group given in Attachment B was established.

Early in 1973, NASA and the National Academy of Sciences jointly decided that it would be appropriate for a special summer study to review the plans for shuttle utilization in the science disciplines. This summer study has now been scheduled for July 1973. It is anticipated that the results of the working group activities to date will form a significant input into this study.

In the following sections of the summary document are the executive summaries of each of the working group reports. While these give a general picture of the shuttle utilization plan, the specific plan in each discipline area can best be obtained from the full report of that working group. Each working group report has been printed as a separate volume in this publication so that individuals can select those in which they are particularly interested.

From these working group reports it is apparent that an appreciable effort has been made to exploit the full capability of the shuttle. It is, however, also apparent that much work remains to be done. To accomplish this important work, the discipline working groups will continue.

Finally it is evident from these reports that many individuals and groups have devoted appreciable effort to this important planning activity. I would like to express my appreciation for this effort and stress the importance of such activities if we are to realize the full potential of space systems in the 1980s.

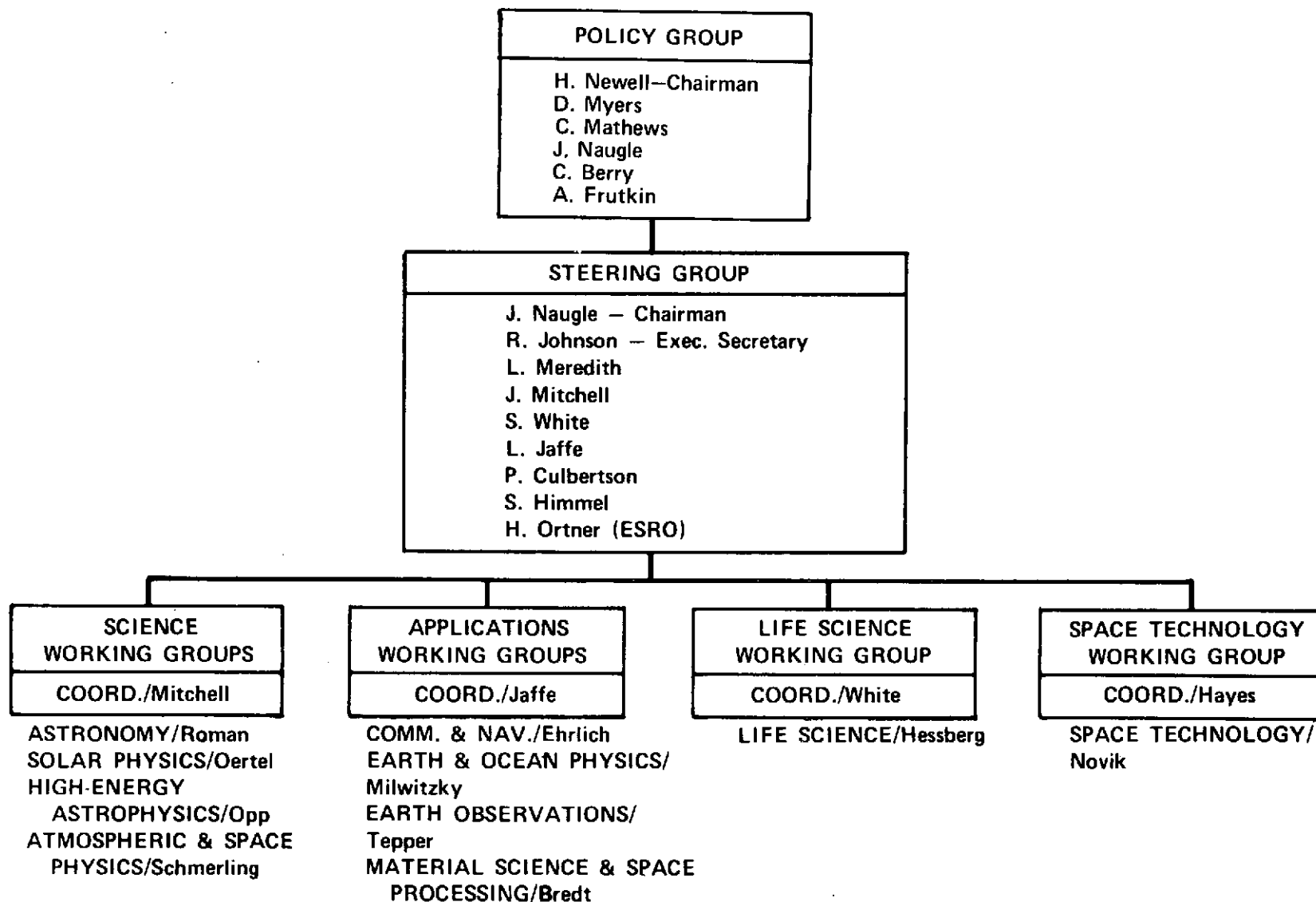
A handwritten signature in dark ink, reading "John E. Naugle". The signature is fluid and cursive, with the first name "John" and last name "Naugle" clearly legible.

John E. Naugle, Chairman
NASA Shuttle Payload Planning
Steering Group

LIST OF WORKING GROUPS

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| 6. | COMMUNICATIONS & NAVIGATION | Mr. E. Ehrlich (HQ) | Mr. C. Quantock (MSFC) |
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NASA AD HOC ORGANIZATION FOR SHUTTLE PAYLOAD PLANNING



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REPORT OF THE NASA SOLAR PHYSICS
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SOLAR PHYSICS WORKING GROUP

EXECUTIVE SUMMARY

This report reviews the present state of knowledge of solar physics and its relevance in the wider astrophysical context. It identifies what appear to be the most promising areas for future work and examines the various ways in which the Shuttle Sortie mode can be used to meet the resulting experimental requirements. A specific solar payload with great scientific potential is proposed as a candidate for an early flight close to solar maximum. In defining this payload we have not considered the current specifications of the Shuttle or Sortie mode of operation as being absolutely fixed, but have outlined the science we would like to do and have identified the demands it places on the Shuttle and Sortie mode, together with the steps that must be taken in the coming months and years to achieve our goal.

Apart from its importance as an object for scientific study, the Sun exercises a profound influence on our planet. Without it, life would, of course, be impossible, but there are other more subtle effects on the terrestrial environment which arise from the emission of plasma clouds and energetic radiations from solar flares. The study of flares by means of space and ground based observations together can provide essential information for understanding the important terrestrial effects of solar activity. At this particular stage solar physics is in an excellent position to take advantage of dedicated Shuttle Sortie missions as part of a balanced program of research using a variety of space and ground based techniques.

Some of the instrumentation optimized for solar physics can also be used with advantage for research in other areas, such as UV, X-ray and gamma-ray astronomy, planetary atmospheres, earth atmospheric studies including the geocorona, the magnetosphere, and pollutant concentration levels, as well as lunar libration point studies and probably still others. It would be difficult, if not impossible, to build a single instrument package optimized for studying all these disciplines. Yet many of them can be profitably explored and better understood with data obtained from a dedicated payload that has been optimized for solar physics. In this connection we hope that the Shuttle Sortie mode will provide easy access for experimenters. It should be possible to get some experiments on board on short notice, as has been the case with sounding rockets in the past.

The Working Group has not discussed in detail the question of what other discipline payloads might be compatible with a Shuttle Sortie for solar physics. It is difficult to do so when the nature of candidate payloads from other areas is

not well known. The solar physics users should meet with other users of the same specific Sortie flight as soon as possible so that the mutual interactions of the payloads can be discussed.

Following the workshop at the Goddard Space Flight Center in August 1972 the Working Group met three times. Its membership was expanded to include four ESRO members, including the Chairman of the ESRO PASOL group, who has provided particularly effective liaison between NASA and ESRO. This group, chaired by G. Oertel of NASA Headquarters with editorial assistance provided by S. Jordan of GSFC, has prepared this report.

The Shuttle Sortie Workshop has begun a dialogue between the Shuttle designers and builders and the user community. This report continues that dialogue. The Shuttle designers should report the actions taken on the recommendations that follow, make counterproposals if necessary, and consult with this group when problems arise. The Working Group considers it imperative that this dialogue continue.

The Working Group has prepared a report which consists of two parts: Part A treats the current status of solar science, its future prospects, and the organizational framework within which these goals might be realized; Part B deals with some of the required technology and the role of man. This report may be summarized as follows.

SUMMARY OF PART A

The solar physics program as a whole, rather than the Shuttle or Sortie alone, has been considered, and a plan has been developed for an orderly evolution from the seventies to the eighties. It is apparent that the scientific objectives in solar physics cannot be achieved with either space or ground based techniques alone, but require both.

A vigorous, continuing solar physics program is essential now and in the Shuttle era to:

- Allow an orderly evolution from existing programs.
- Maintain a viable solar physics community.
- Take advantage of the 1979 solar maximum.
- Develop now the instruments to fly in the eighties.

The relationship of solar physics to other disciplines such as fundamental physics, cosmology, high energy astrophysics, dynamics of stellar atmospheres, and plasma and atomic physics, as well as studies of the magnetosphere, planetary atmospheres, meteorology, and other applied areas was considered. Two types of contributions are made by solar physics: knowledge about solar phenomena will stimulate progress in some of these areas, and vice versa; instruments designed for solar observations can be used for other studies such as extinction in the earth's atmosphere and observations of cosmic objects.

Four major areas where future investigations should be more intensively conducted have been selected. They cover four important problems that solar and stellar astrophysicists are now faced with:

- The production of mechanical energy in the subphotospheric layers and its transport and dissipation in the upper layers of the atmosphere.
- The mass flux from the subphotospheric layers into the chromosphere and corona and beyond via the solar wind.
- Solar activity and its relationship to magnetic fields.
- The production of solar flares.

Some specific problems have been outlined and the relevant critical observations have been discussed. The need for a problem oriented approach and for coordinated observation over a broad spectral range has been stressed, as well as the need for improved spatial, spectral, and time resolution. It has been pointed out also that adequate absolute photometric accuracy is of extreme importance.

Four categories of Shuttle utilization have been developed. Two (classes 1. and 4.) are major evolutionary steps from existing programs, two are entirely new approaches. Each contributes uniquely to the solar physics objectives which have been identified. They are:

1. The class of experiments currently supported by OSO spacecraft requires 1 to 5 arc second pointing stability over less than one hour, and life times of the order of years. This class of experiments should be supported by a single low cost free flier in the Shuttle era, through revisits, with maintenance and substitution of experiments as appropriate. The Shuttle can also serve as a continuously available ground station, for periods of hours to weeks, to carry out special operations at high data rates or to select special targets in real time. Easy maintainability, repairability, and experiment substitution are essential in this context. It is also essential that this free flier spacecraft be developed as soon as possible for flight in 1977 or 1978, in time for the last solar maximum before 1990.

2. The next larger class of experiments will ultimately fly on a free flying Large Solar Observatory (LSO) some time in the eighties, but to do this requires developmental, verification, and sample data acquisition flights prior to commitment to LSO. The Shuttle Sortie mode is ideally suited for this purpose, provided the required interface quality can be attained in terms of weight, power, data, pointing, freedom from contamination, etc. An exciting sample Sortie payload has been developed complete with detailed interface requirements. It has the objective of studying solar activity, flares, and flare associated phenomena and consists of experiments requiring continuous solar pointing in two classes: highly sensitive high energy instruments which require only coarse pointing and are relatively insensitive to contamination; complementary instruments for infrared, visible, UV and soft X-ray spectroscopy and imaging which require fine pointing and are generally more sensitive to contamination and pointing instability.

The instruments in this payload can also attain the objectives of the ESRO solar group which are generally in the quiet sun area. This commonality of instruments is achieved through flexible data acquisition modes and offers the exciting potential of developing different parts of the payload in the U.S. and abroad for joint experimentation. It is clear that this will require assurance to foreign contributors that they will have access to the future free-flying LSO.

3. The LSO itself is envisioned as a free flying large platform for some coarse pointed and some fine pointed experiments, rather than a single large telescope of some sort. It is a development for the eighties and should be capable of handling at least the class of instruments described in the sample Sortie payload. It could evolve from the free flier if low cost growth potential is built in.
4. The fourth category features the lowest cost and is the simplest, but it is also most exciting and promising. It maintains the advantages of the current sounding rocket operation, such as short development time for new concepts, short turnaround, minimum cost, and great flexibility and potential for broad participation by students and experienced experimenters alike. The Shuttle will extend the available observing time by orders of magnitude and reduce the cost per data element by a similar factor, while providing even greater flexibility in instrument accommodation.

A support package could be evolved from existing solar pointers, such as SPARCS, for single experiments, which could be cast overboard by the Shuttle and recovered, or deployed on a boom or gimballed mount. Alternatively, a

single "pallet" type platform could support several experiments simultaneously. These alternatives should be studied as soon as possible. The Sortie lab as well as possibly the eventual deployment of an LSO will require dedicated missions. Visits to the subsatellite and the sounding rocket class experiments can take advantage of, but do not require, a dedicated mission. They should also be considered for missions dedicated to other disciplines.

A low cost, high efficiency approach is mandatory and should be a major objective of the evaluation for the Shuttle. Highest efficiency has been obtained in areas where the scientist has had maximum control and has worked under well defined, fixed funding limitations such as in the sounding rocket program. The role of the scientist must therefore be maintained or strengthened, while limiting absolutely the funds he is allowed to expend. This is likely to be practical in solar physics where a variety of instruments make up a payload rather than a single large instrument. Documentation and other requirements on the scientist must be minimal and reduced by at least an order of magnitude from present orbital programs.

The operation of all but the smallest, exploratory instruments must be in some kind of "facility mode" to provide access to the data for all qualified solar physicists. This has been achieved, for example, through guest investigator programs in OSO-I and ATM while maintaining the current flexible and proven management approach. The allocation of a fixed percentage of observing time to guest investigators will be considered, depending upon the flexibility of the payload and the duration of orbital operations.

SUMMARY OF PART B

The observational requirements were considered from three points of view: general requirements, requirements as a function of spectral regime, and requirements for new technology. Important general requirements include the need to co-align a number of separate instruments to facilitate common object viewing and the need to carry at least a simple calibration facility on the Shuttle to ensure optimum absolute photometric calibration during operation in orbit. Specific spectroscopic and photometric requirements were established for the infrared, visible, UV, XUV, soft X-ray, hard X-ray and gamma-ray spectra. The neutron flux was also discussed. A listing of needed advances in instrument technology was generated, including the development of instrumentation to provide high resolution magnetic field measurements simultaneously with the spectral data.

Several categories of space platforms were discussed. There will be a continuing need for the types of platforms currently represented by sounding

rockets, balloons, and aircraft, as well as the type featured in the OSO series of unmanned solar observatories, referred to here as semi-automated pointing platforms. All these types can be orbited and serviced efficiently by the Shuttle. In addition, moving toward the LSO of the eighties, large finely pointed and coarsely pointed platform requirements were discussed.

The role which man might be expected to fill in operating and maintaining a complex solar instrument package in the Shuttle was considered in detail, and requirements for both a Flight Scientist as well as a Technician in orbit were determined. The possibility that a single astronaut could fill both roles was also considered.

The data transmission rates for the Shuttle solar experiment were determined to vary from a peak rate of 10^7 bps over short time intervals to a steady rate which might be as much as two orders of magnitude lower. Some of the problems involved in real time viewing of simultaneous solar images were considered. The Working Group strongly endorsed use of the data relay spacecraft system.

Finally, a tabulation of anticipated flight requirements for the seventies and eighties was generated, followed by the assembly in four Appendices of further requirements and operational procedures for the four classes of experiments for Shuttle utilization described in the previous Summary to Part A.

PART A

SCIENTIFIC AND ORGANIZATIONAL ASPECTS OF
SOLAR PHYSICS EXPERIMENTS

OVERALL RECOMMENDATIONS

PROSPECTS

The Space Shuttle offers exciting prospects for significant advances in space experimentation that will revolutionize solar physics and many other disciplines of space science. Properly planned and executed, the Shuttle Sortie mode of operation will permit dramatic increases in the capabilities and returns from both free flying and attached platforms that will evolve from current programs and from others that can be designed specifically from the Shuttle and be first flown in the Sortie mode.

SOLAR MAXIMUM MISSION

In order to take advantage of the last solar maximum before 1990, a solar maximum mission for the study of flares and associated phenomena should be developed now and launched in the 1977-1978 time period. This mission may be visited and refurbished as a semi-automated free flying solar platform in the Shuttle era.

SEMI-AUTOMATED FREE FLYING SOLAR PLATFORM

Recognizing the importance of achieving high angular and spectral resolution in the UV, XUV, and X-ray regions, the group recommends that priority should be given to the evolution from the latest solar spacecraft of the 1970's to a Shuttle serviced platform with comparable capability plus interchangeability of instruments. Such a platform should be controllable from either the Shuttle or ground and have an unattended life of at least three months.

CONTINUITY OF SOLAR PROGRAMS

In order to exploit the opportunity offered by the Shuttle, it is essential that there should be a strong, continuing program of solar research. In particular, NASA is urged to continue support for the following:

- OSO-I, -J, -K
- Sounding rockets
- Balloons

- Ground-based observations
- Data analysis and interpretation
- Supporting research and technology

PROBLEM ORIENTED APPROACH

The Working Group recommends that major studies of solar physics using the Shuttle should be undertaken as a problem-oriented activity, including observations from ground-based observatories, sounding rockets, balloons and other Shuttle associated experiments. In addition, "sounding rocket" type Shuttle payloads should be flown as independent exploratory experiments.

INVOLVEMENT OF THE SCIENTIFIC COMMUNITY

In order to ensure maximum participation by solar physicists any large (ATM class) instrumentation in space should be operated as a national facility and the solar physics community must be directly involved in the design, coordination, construction and operations phases of the instruments. In return for the effort invested in this way, the investigators should receive an appropriate share of the observing time. The instrumentation and responsible investigators should be selected by open competition from the entire scientific community.

LONG LEAD-TIME DEVELOPMENTS

In order to fully realize the potential of the Shuttle for solar research it is important that development of current instruments and the evolution of new ones should take place in parallel with that of the vehicle. Development of long lead-time instruments, components, and technology should begin at once.

INTERFACE BETWEEN SCIENTIFIC INSTRUMENTS AND THE SHUTTLE

The group recommends that telescopes or other light gathering devices should always be considered part of the scientific package.

CONTAMINATION

The Working Group finds that the environment of the Space Shuttle as presently conceived (February 1973) is unacceptable for many major Shuttle-based solar observatories. It is therefore recommended, with the greatest urgency, that all sources of gas, vapor and particle contamination should be eliminated to the maximum extent possible both from the Shuttle itself and from the environment of the instrumentation prior to launch. The Working Group encourages and offers to cooperate with a comprehensive study of the overall contamination problem on the Shuttle.

ADAPTATION OF "SOUNDING ROCKET" CLASS EXPERIMENTS TO THE SHUTTLE

The Working Group strongly recommends that every effort be made to adapt sounding rocket, aircraft, or balloon class hardware for use with the Shuttle. This could lead to the lowest cost method of conducting solar work in the Shuttle and could significantly extend the observing time.

PLATFORM DEVELOPMENT

Solar physics will eventually require angular resolutions approaching 0.1 seconds of arc. It will further require a platform capable of supporting large and heavy instrumentation. The image stability must be at least as good as the angular resolution. We recommend that a multi-disciplinary platform, attached or free flying, be developed that can support any one of the solar instruments identified, and indeed, as many as possible simultaneously. It should be made as stable as possible to reduce the cost and complexity of any image motion compensation within the instruments.

PAYLOAD DEVELOPMENT AND VERIFICATION

The committee recommends that a vigorous program of verification flights, using balloons and sounding rockets, be established, when appropriate, to confirm critical design concepts and to define optimum levels of instrumental sensitivities.

QUALITY ASSURANCE

The Working Group recognizes that a significant relaxation of present quality assurance requirements is mandatory if the Shuttle Sortie mode of operation is to be at all attractive, cost-effective, and affordable. We recommend that, rather than depend on formal documentation, the responsibility of scientific instrument performance be placed on the builder of the instrumentation who will be motivated by his desire to obtain useful data and thus to get future flight opportunities.

ON BOARD DISPLAYS

To provide man with the capability to choose suitable objects for study as well as to recognize changes in the phenomena under study, the Shuttle Sortie Laboratory operational consoles must have a sophisticated recallable data bank. This should include strip chart recorders and short term image storage, both video disk or tape, and hard copy. A solar monitoring package usable on all solar Sortie missions should be developed to display, for example, 8.8 GHz and 20 MHz solar radio bursts, hard X-ray flux, and, if possible, full disk XUV.

The number and capabilities of the mission and payload specialists will influence the data requirements for supporting a given mission to a considerable extent.

DATA MANAGEMENT

In order to manage the very large quantity of data collected by a solar imaging device on the Shuttle or its substatellites, we recommend that the following facilities be provided as part of the Shuttle data management and communications system:

- On board magnetic tape recording and computing facilities.
- Film recovering capability from the Shuttle's substatellites.
- On board film storage and handling.
- Data relay spacecraft system providing a minimum data rate of 10^7 bits/second of continuous, real-time, TV transmission from the Shuttle and its substatellites to the ground.

DATA REDUCTION AND ANALYSIS

To ensure the prompt and efficient dissemination of the experimental results, it is mandatory that adequate funding be made available to the scientific investigators for the reduction, analysis and interpretation of the solar data obtained.

ORBITS

Some solar physics Shuttle Sortie missions will be best carried out from high inclination, sun-synchronous orbits which allow continuous solar viewing. We recommend this option be maintained, keeping in mind that data retrieval and a possible decrease in observing time in the UV at high inclinations do pose problems. If the orbit perigee lies above 650 km, the residual atmosphere extinction is 10% at 80° orbit inclination.

TIMING OF SOLAR MISSIONS

Because of their short duration it is important that Shuttle Sorties for active sun studies be scheduled with enough flexibility so that a payload could be quickly launched to take advantage of the appearance of unusually large and active sun-spot groups.

SOLAR STUDIES IN PERSPECTIVE

DISCUSSION

The Sun is our star, the source of our heat and life, and its radiative and particle output affects all disciplines concerned with the solar system. As the only star we can study in detail, it provides, in Schwarzschild's words, a "Rosetta stone" for the understanding of many physical processes in other stars. In a manner quite analogous to the way quantum theoreticians have used the hydrogen atom to check new ideas and techniques before applying them to other atomic systems, astrophysicists can use the Sun to check new ideas and techniques in radiation transfer, atmospheric heating, flare phenomena, and stellar mass loss (winds) before applying them to other stars for which data are less complete or more difficult to interpret. In this sense, the Sun serves as "the hydrogen atom of astronomy".

The exotic objects recently discovered by X-ray and radio observations provide an example of how solar studies may be useful. The scarcity of observational

data has led to the proliferation of numerous speculative models for these objects, whereas careful studies of solar flares may provide valuable information to permit a more discriminating choice. A solar flare induces high energy processes, such as the generation of hard cosmic rays and associated radiation extending over the spectrum from the gamma-ray range to radio wavelengths. Thus, we have nearby a laboratory where many processes which may prove fundamental to the exotic, new objects can be studied in considerable detail.

The current controversy over the Dicke gravitation theory seems to be most readily resolvable by measuring the solar oblateness to high accuracy. To do this requires a more detailed knowledge of the solar surface than currently exists, particularly of pole-equator differences in temperature, scale height, and activity.

In the realm of stellar structure and nuclear reactions, as well as, possibly, elementary particle physics, the problem posed by the surprisingly low solar neutrino flux measurements promises to stimulate thinking which could have profound implications for stellar evolution as well as basic physics.

The cosmic abundance of the elements is a critical parameter in any theory of the origin and evolution of the universe. Measurements of solar abundances provide the baseline for understanding cosmic abundances. Some of the relevant measurements must be made in the UV and XUV spectral range. Abundances evaluated using OSO 4 and 6 data are now commonly used in astrophysical calculations.

Studies of the solar atmosphere have produced theoretical methods, like non-LTE theory, which have been applied successfully to both early-type stars with hot, very extended atmospheres as well as late-type stars like the Sun. Hydrodynamical phenomena in the solar atmosphere, both with and without magnetic fields, are currently subjects of vigorous research activity. Many of the forthcoming results will probably find application to interpreting spectra from other stars. In particular, as more is learned about the heating of the solar chromosphere and corona above the temperature minimum, more can be learned about the mechanism producing temperature reversals and extended atmospheres in other stars. The empirically determined Wilson-Bappu effect can then be understood.

Stellar winds and many details of mass loss mechanisms should be clarified by continuing studies of the solar wind. The process whereby the solar wind removes angular momentum from the sun, thus slowing down the solar rotational velocity, is basic to an understanding of the origin and evolution of both the Sun and our solar system, and, by extrapolation, other stars and planetary systems.

The mass loss problem is particularly important in determining the composition of the interplanetary plasma as well as the interstellar medium.

Two fundamental physical parameters that determine the thermal structure, the composition and the dynamics of the earth's and other planetary atmospheres, are the spectral distribution and intensity of the solar radiation. These data are needed not only in detailed theoretical calculations, but also in the interpretation of results obtained from automated spacecraft.

Closely related to atmospheric studies are efforts to understand subphotospheric convective transport in the sun. We may expect that further observations of the supergranulation will shed new light on the physics of the convection zone, which, in turn, should enable us to improve the structural models for late-type stars. Also, the material in the supergranulation network appears to be oscillating at periods around 300 sec. This is now thought to arise due to instabilities in the upper convection zone. Further, observations of such periods have recently been made in low coronal lines seen by OSO-7. Hence, the possibility exists that these oscillations may play a dominant role in atmospheric heating. If so, the Sun may provide us with a comprehensive and coherent picture of the coupled convection and heating process which would have widespread relevance to many other stars.

Much of our current understanding of low density plasma has come from or been stimulated by solar studies. This includes work on the excitation, ionization, and recombination of dilute plasmas. For example, the importance of dielectronic recombination was first recognized in the solar corona. It is now considered important in the excitation of interstellar radio lines. Also, since it is difficult to obtain low density laboratory plasmas of sufficient path length to observe forbidden transitions, many of these have been seen only in the solar spectrum. Such transitions can provide methods for measuring electron densities, and they are observed in other astronomical objects, including planetary nebulae, Seyfert galaxies, and quasars.

The importance of understanding solar flares has already been mentioned in relation to physical mechanisms which may operate in pulsars and quasars. There is an enormous variety of important questions which could be clarified, if not answered, by a better understanding of the solar activity cycle and of flares. For example, regarding activity:

- How is the cyclic solar magnetic field related to solar convection and differential rotation?
- How does this coupling affect the loss of angular momentum now?

- How did these processes act in the past?
- What are the implications for the structure and evolution of other stars?

Few detailed observations are currently available of the short-lived explosive phase of solar flares. Much of the flare energy is released as kinetic energy of outward expansion of material. However, the origin of this explosion has not been located, and the crucial physical parameters involved in triggering it have not been determined. To do so, an experimental package combining a quick look capability with high spatial and time resolution in several carefully selected lines, including, of course, $H\alpha$, is needed. Given such an experiment, it may be possible to determine not only the critical flare mechanisms, but also insights toward the solution of a number of related problems in magnetoplasmodynamics.

Finally, as man's technical achievements mount, the importance of solar-terrestrial effects will grow. This is particularly likely if solar energy is tapped as a power source. In addition to the well known solar activity effects on radio communication, there are now well documented effects on long distance power lines, telephone lines, and safety factors for flight above the atmosphere. The ability to predict the occurrence of major flares, which we currently lack, would have great economic benefits and may determine the extent to which man can work in space above the atmosphere. We can certainly expect that any improvement in understanding the physics of flares will lead to an improvement in our predictive ability.

This section represents a brief summary of some ways in which an increase in our knowledge of the Sun might impact other scientific disciplines, as well as future technology.

Just as the Hubble Constant must always be normalized to the distance of nearby Cepheids, many of our ideas on stars and the physical phenomena of the universe will have to be normalized to what we see on the Sun and what we learn about it.

SOLAR PHYSICS TODAY AND DIRECTIONS FOR THE FUTURE

PRESENT SITUATION

Much of the current effort in solar research aims at improving our understanding of the physical processes occurring in the following areas:

- The production of mechanical energy in the sub-photospheric layers and its transport and dissipation throughout the chromosphere, corona and solar wind.

- The transport of material within these layers of the solar atmosphere and out into the solar wind.
- Solar activity and its relationship to magnetic fields.
- The production of solar flares and, in particular, the non-thermal flare-associated events.

If one notes that a knowledge of the atmospheric structure (temperatures, electron densities, etc., as a function of position and, when relevant, time) is required for progress in these four areas, one can see that they encompass practically all of the problems treated by solar physics, except for the study of nuclear energy generation in the core.

Energy Production, Transport, and Dissipation

The sources of mechanical energy heating the chromosphere and corona lie within and at the top of the sub-photospheric convection zone. Observations of the brightness variations and velocity fluctuations associated with features such as the granulation and super-granulation network have provided valuable information on the structure and dynamics of this convection zone. Recently constructed telescopes are now extending the spacial resolution of such observations to the practical limits imposed by ground-based seeing. For example, recent observations have revealed the existence of a previously unsuspected 'filigree' structure in the granulation, having a characteristic scale of < 0.25 arc sec; this scale is at the foreseeable limit of resolution from the ground.

Recently, high resolution magnetographic observations have indicated that the greater part of the total magnetic flux outside active regions is concentrated into very small areas of high field strength within the chromospheric network. Spicules are also observed to originate in the network area and must contribute not only to the energy balance but also to the mass transport throughout the solar atmosphere. Also, the channeling of the mechanical energy flux by the magnetic fields and the existence of spicules have important implications for the structure of the chromosphere and corona above.

Recent observations of line widths in the chromosphere and the transition region suggest the existence of non-thermal motions which may, for example, be associated with the passage of acoustic waves through the atmosphere. In fact, there are compelling theoretical and observational considerations pointing to the heating of the chromosphere and corona by acoustic, magnetoacoustic, and, possibly, also gravity waves, which are generated by mechanisms in the convection zone or just above it. The compressional modes are thought to heat the

gas by shock dissipation. However, some other mechanism is required for the gravity mode if, in fact, it plays any role at all.

One necessary step in investigating the processes of energy transport and dissipation is the construction of detailed empirical models which specify the physical parameters as a function of position and height in the atmosphere. It has been possible to construct fairly consistent average models of the solar atmosphere from observations thus far made from the ground and from space experiments. It is found that after a fall to a minimum temperature of about 4500°K , some 500 km above the photosphere, the temperature at first rises gradually to about 8000°K ; then it rises very rapidly to about $5 \times 10^5^{\circ}\text{K}$ with this narrow transition zone occurring at a height of about 2000 km above the photosphere. Above the transition region the temperature gradually reaches an average temperature of about $1.6 \times 10^6^{\circ}\text{K}$. However, it is recognized that the steep temperature gradient leads to a situation in the low transition zone where, in a spherically symmetric atmosphere, the energy conducted back from the corona cannot be disposed of by radiation. The direction of the magnetic fields and local motions of the atmosphere will surely play an important role in the energy balance. Thus, the average models available now can be considered only as a starting point for future observations.

Mass Transport

The mass flow from the solar atmosphere is observed in interplanetary space as the solar wind. Since this outflow originates from a corona which is far from spherically symmetric it is not perhaps surprising that it is far from constant in magnitude to an observer on earth. It is important to know the interaction between the features observed in the solar atmosphere and the overall mass flow from the Sun. For example, observations to date have shown an enhanced flow of material from the coronal streamers. Recent rocket and satellite experiments have shown the existence of coronal 'holes', i. e., regions where the electron pressure is substantially lower than in the surrounding corona. Differences in the structure of the atmosphere are not limited to the corona but extend to at least the transition regions, where a lower temperature gradient implies a decreased energy flow by conduction down to the chromosphere. Coronal holes are important both in the study of coronal heating and of mass flow and may be related to the source of the solar wind. On a smaller scale, prominences and spicules show motions which must surely play a role in the mass transport cycle within the solar atmosphere. This role is only beginning to be explored.

Solar Activity

The phenomena associated with regions of enhanced magnetic fields in the photosphere and low chromosphere can be observed in the visible and infra-red parts of the atmosphere. As the spatial resolution obtainable in the visible region has improved, smaller features have been observed. In particular, sunspots have been studied with renewed interest following the discovery of umbral flashes and running penumbral waves (Stein waves). The enhanced magnetic fields associated with sunspot groups extend far into the corona and their configuration can be implied from the loop structures and position of the emission observed in photographs made in the X-ray and ultraviolet parts of the spectrum. In the chromosphere, transition region, and corona, the active regions appear as enhancements in electron density and temperature. Calculations on the structure and energy balance show the need for a greater mechanical energy input in these regions than for quiet regions.

The sunspot cycle has been the subject of many observational and theoretical studies. The observational phenomena associated with it (e. g., sunspot numbers and motions, the magnetic field strengths and distribution) are well known within the present limits of spatial resolution. A rather comprehensive theoretical model for the solar magnetic field has been advanced by Leighton and his co-workers at the California Institute of Technology. This theory assumes that the solar field is due to the effects of differential rotation on convective motions beneath the photosphere. When the resulting magnetic field is sufficiently "wound up" (i. e., strong), it pops through the surface as an active region and, in some cases, as a sunspot. The theory predicts many observed features of the solar cycle and provides an alternative to older notions based on a "frozen in" dipole field which, somehow, reverses polarity every eleven years. Ultimate determination of the correct field mechanism may depend upon high resolution field measurements taken over a period of a week or more in order to determine, for example, how an active region breaks up or diffuses at its boundary.

Solar Flares

The production of solar flares and the associated transient phenomena is an exciting area of physics still posing many unanswered questions. Observations of flares in the $H\alpha$ line have, over the years, provided a wealth of information on the changes in an active region before, during, and after a flare. The relationship between the appearance of a region in $H\alpha$ and the local magnetic fields has also been studied in careful detail. The observations of changes in the structure in $H\alpha$ can be used to imply the existence of other physical processes. For example, the existence of transverse MHD waves travelling outwards from the location of a flare can be deduced from the oscillations of quiescent filaments some distance from the flare.

The thermal part of the flare plasma has been observed from experiments made in the visible, XUV and soft-ray regions of the spectrum and from observations of the slowly varying emission at cm wavelengths. The non-thermal phase of the flare has been detected from hard X-rays, γ -rays and impulsive bursts at cm wavelengths. The interaction between the rapidly moving flare plasma and the surrounding corona can be studied from the emission at meter wavelengths. Recent measurements of nuclear gamma-ray line emission have shown the acceleration of protons in the early phase of a flare. Polarization measurements at energies greater than 0.7 keV have indicated the presence of non-thermal electrons; such measurements can be used to give the direction in which the electron beam is guided in the solar atmosphere.

As is well known, the big problem can be stated simply: What is the mechanism (if, indeed, there is just one) which triggers this energy release over such a broad spectral range, and how, in detail, is the energy transformed among the numerous modes involved? In short, we still do not know how a flare works.

FUTURE AREAS OF STUDY

In the previous section our present understanding of several important general areas of solar physics was summarized. Some corresponding unsolved problems will now be discussed.

Energy Production, Transport, and Dissipation

Solar granulation is of particular interest here because it forms the upper boundary to the hydrogen convection zone, which emits the mechanical energy needed to heat the corona and chromosphere. Features and physical processes for which further study may clarify the basic energy production and transport mechanisms are as follows:

- The power density spectrum of brightness fluctuations at spatial frequencies $k \geq 5 \times 10^{-3} \text{ km}^{-1}$ ($\lambda \leq 200 \text{ km}$)
- The development and structure of velocity fields in the granulation and their relation to fluctuations in photospheric magnetic fields
- The time scale for the evolution of individual granulation elements
- The temperature and density inhomogeneities in photospheric granulation
- The newly discovered 'filigree' structure and its relation to other photospheric phenomena

- The development of solar faculae from their birth to their disappearance
- The development and structure of velocity fields associated with super-granulation and its correlation with the chromospheric network and magnetic fields
- The temperature and density structure of spicules, their motions and relationship to local magnetic fields
- The interaction between the granulation, oscillatory motions, and wave phenomena in the photosphere and chromosphere
- The 3-dimensional density, temperature, and magnetic field structure of the network

Although it is generally agreed that the chromosphere and corona are heated by waves originating in and above the subphotospheric convection zone, problems still not understood well are:

- The details concerning the types of waves which are important
- The dissipation mechanisms
- The roles played by conduction and convection at each level of the atmosphere

The role of the spicules, both in the energy balance and mass transport cycle, is not at all clear. Although the supergranulation network is observed to extend to the transition region, the relation between the areas observed in enhanced emission, the magnetic field configuration, and the energy balance processes must be clarified by further observations. Departures from these average models which give the physical parameters describing the state of a hypothetical, spherically symmetric chromosphere and transition region are not known quantitatively.

The directivity of non-thermal motions observed in the chromosphere and transition regions has not yet been observed, nor have wave-frequencies and phase-correlation distances. Thus, the type of wave motion or turbulence to which they are related is not yet settled. Further studies of these motions are of great importance since they may transfer mechanical energy to the corona and cause sufficient local temperature and density fluctuations in the atmosphere to modify the interpretation of the XUV emission line intensities. Observations of the variations of all of the fundamental parameters as a function of latitude are needed to clarify the interaction between photospheric features and the structure of the corona.

Mass Transport

The following aspects of coronal features should be studied:

- Evolution of coronal streamers and arches
- Density distribution and energy flow in streamers and open field regions, including coronal 'holes'
- Rotation of coronal structures compared with photospheric rotation rates
- The relationship between coronal forms and fluctuations observed in the solar wind high speed streams, shocks, etc.

Further observations that are needed for the understanding of prominences are:

- The structure of the corona and quiescent prominences
- The 'condensation' of coronal material
- The relation of prominences to streamers
- Plasma sheets and magnetic field annihilation
- The development of helical magnetic fields

Solar Activity

Unfortunately, activity on the sun has decreased at the same time that the observational capability of space platforms has improved. As the present solar cycle declines, observations of the corona made with 5 arcsec resolution and observations of active regions made with 10 arcsec resolution will become available from OSO-7 and ATM-A. However, the possibility of studying transient events and the number and variety of observable active regions will be limited. Therefore in order to understand the complex, active Sun it is essential to make a concerted effort to obtain observations during the rise to the next solar maximum.

At photospheric levels the observations made so far of sunspots raise some tantalizing questions. For example:

- What is the origin and role of the running penumbral (Stein) waves?

- What causes the umbral flash?
- Do real differences between umbrae exist or are apparent variations due to different numbers of umbral dots? If real, do they represent an evolutionary effect?
- What elements in the penumbra contain the Evershed flow?
- What is the physical explanation of the flow and the observed bright elements?
- What is the exact role played by small-scale magnetic fields in determining the sunspot structures, e.g., the pressure equilibrium?

In the chromosphere, transition region, and inner corona, progress has been made in determining the temperature, densities and their gradients in active regions. However, the spacial structure of active regions is extremely complex and changes completely in the higher layers, where the magnetic field dominates the situation. The location of the hottest regions may, for example, be in small spots or in the centers of filamentary structures. The formation, heating and long-term development and decay of active regions all require further study. In particular, the origin of the enhanced mechanical energy flux reaching the corona above an active region remains to be understood and explained in terms of the observed photospheric features and magnetic fields.

Solar Flares

As emphasized previously, solar flares have an important impact on the conditions in the earth's ionosphere. The importance of a future opportunity to closely study the high energy and non-thermal processes which occur in flares (and which may also be important in other fields of astrophysics) should not be underestimated.

Most of the unknown aspects of solar flares relate to the impulsive non-thermal phase of flare development, which is the main phase during which the acceleration processes in the flares are thought to occur. Some questions relating to particle acceleration in flares are as follows:

- Where is the specific location of the primary acceleration?
- What are the magnetic and electric field configurations in the flaring region? To what extent are the fields force-free? How large are the electric currents? Is the flare related to changes in these quantities?

- Is the primary acceleration due to current interruption or to an instability in a gradually built-up concentration of energetic particles?
- What are the relative positions of the sources of X-ray, radio waves and optical emission?
- Is the optical flare a secondary effect of the high energy flare?
- At what time does particle acceleration occur, and is this a single or double stage process?

These questions relate mainly to understanding the flare once it has begun.

Another area of current interest concerns the state of an active region prior to the occurrence of a flare. There is evidence that coronal structures build up above an active region during several hours or days prior to the occurrence of a large solar flare, and that the X-ray, XUV and radio emission from such a region tend to increase in intensity during this period. Further, accelerated particles of comparatively low energy are observed to escape from the build-up area into interplanetary space. Many aspects of the build-up and later flare processes are not understood and further observations of particle densities, fluxes, temperatures and of magnetic fields and their variation with time, are needed. For example:

- Are the observed copious quantities of low-energy accelerated particles produced and held in more or less leaky storage by a process which is continuously in operation during the build-up?
- How, when, and where, are the higher energy particles observed during the flare produced?
- Have they also been held in storage for some time prior to the flare or are they the sudden second step of a two-stage acceleration process?
- What causes the observed leakage and what triggers the flare?

FUTURE OBSERVATIONS

The critical observations needed to answer the questions posed in the preceeding section are discussed here. For many areas of interest it is essential to take a problem oriented approach and make coordinated observations over a broad spectral range with spatial resolution adequate to resolve the fine structure of physical significance. Several questions can be resolved only by making observations with high spectral and temporal resolution as well. In this section the necessary future observations and critical requirements are listed.

Energy Production, Transport and Dissipation

In order to provide further information on the dynamics of the hydrogen convection zone, the following observations are needed:

- Long-term time-lapse observations made in the visible region of the

spectrum with high spatial (< 0.2 arcsec), spectral ($\lambda/\Delta\lambda = 5 \times 10^5$ at 5000\AA) and temporal (< 10 secs) resolution.

- The intensities, velocity fields and magnetic fields should be measured in features such as granulation, supergranulation, and filigree structures. The infra-red part of the spectrum may prove useful for making measurements of magnetic fields because of the λ^2 dependence of the Zeeman effect, but the spatial resolution obtainable will be lower.

Problems which limit the ground-based observations in the visible part of the spectrum have been discussed in the recent ESRO PASOL Report.

The transport of mechanical energy from the photosphere to the chromosphere and corona should be studied with high spatial (< 1 arcsec) observations of:

- the widths and profiles of lines formed in the chromosphere (visible and EUV spectral regions), transition region, and corona (EUV and soft X-ray spectral regions); a spectral resolution of 3×10^4 is needed;
- the variation with time of the total intensities of lines formed in the chromosphere, transition region, and corona; a time resolution of about 10 secs is needed;
- the variations with time of the mean line center wavelengths and profiles of emission lines formed at the different heights in the chromosphere, transition region, and corona;
- the center to limb variations of the above quantities; and
- their variation with latitude.

To study the densities and temperatures over the full height of the solar atmosphere, it is necessary to observe, with high spatial resolution (< 1 arcsec) the following:

- the absolute intensity of the continuous emission in the infra-red region of the spectrum (1.6μ to 100μ), and the continuous emission in the region 1500\AA to 1700\AA . These quantities give information on the structure of the atmosphere in the region of the temperature minimum. Also needed are the various recombination edges in the region 1200\AA to 2800\AA , and of the Lyman continuum (below 912\AA) and neutral helium continuum (below 504\AA), and simultaneous observations of several EUV and soft X-ray emission lines formed in the transition region and corona;

- the relative intensities of: emission lines which are sensitive to the electron density (e.g., those of the Be I-like ions); emission lines which are sensitive to the electron temperature (e.g., those of the Li I-like ions and Be I-like ions);
- the center to limb variations of the above quantities including above-the-limb observations.

High spatial resolution is needed in order to correlate the spatial distribution of the EUV and soft X-ray lines with the supergranulation network. The accuracy desired for absolute intensity measurements is 10%, to match the accuracy to which the atomic data may be known by about 1980. Relative intensity measurements should be made to within 5% in order to determine N_e and T_e with sufficient accuracy.

Mass Transport

In addition to the observations listed above to measure the dynamics of the solar atmosphere, the mass transport through the solar atmosphere should be studied from:

- time lapse studies - filtergrams, spectra and line profiles of spicules at the solar limb, prominences and coronal streamers;
- measurements of electron densities in coronal features;
- correlation with observed parameters of the solar wind and interplanetary medium.

Active Regions

The study of active regions requires a wide variety of observations which must be spatially correlated over a broad spectral range.

The observations listed for studies of heating and dynamics of the 'quiet' atmosphere are also needed for regions of enhanced magnetic field. In addition to these observations, the following requirements can be listed:

1. To study the interaction of rising magnetic fields with the solar plasma within the photospheric layers, long-term time lapse observations are needed of:
 - the velocity fields as an active region develops;

- the strength and structure of the fine-scale magnetic fields from the first development of pores;
 - the brightness fluctuations of small-scale features in sunspot umbrae and penumbrae.
2. In the chromosphere, transition region, and corona, the main requirement is to quantitatively study the differences between the quiet and active regions. Magnetic field measurements at these heights would be extremely valuable, but no reliable way of making them is yet apparent.
 3. The solar spectrum between about $\sim 40 \text{ \AA}$ and 8 \AA is predominantly formed in coronal active regions. Specific requirements for the study of the high temperature components of active regions are high spatial resolution measurements of:
 - the absolute intensities of the emission lines;
 - relative intensities of lines which are sensitive to the electron density (lines of the He I-like ions), and lines which are sensitive to the electron temperature (e.g., lines of the He I-like and Li I-like ions);
 - line widths to determine ion temperatures (A spectral resolution of $\sim 6 \times 10^3$ at 10 \AA would be necessary);
 - the spatial distribution in selected lines or wavelength bands to determine the temperature structure and to deduce the magnetic field configurations.

The above observations should ideally be made over the lifetime of an active region, but observations over a week would still be of value.

Solar Flares

The thermal plasma associated with flares can be studied from observations in the visible, XUV and soft X-ray regions and from the slowly varying emission at cm wavelengths. These observations are essentially the same as those listed above for active regions with the added need here of the ability to measure rapid time variations.

In addition, the spectrum around 1.8 \AA to 2 \AA is formed in solar flares and contains many lines which can be used to determine T_e and departures from ionization equilibrium in the flare plasma. The spectral resolution to study both the relative intensities and line profiles of these lines is $\sim 6 \times 10^3$.

There are several ways in which the non-thermal phase may be observed. It can be detected through:

- hard X-rays, with energy greater than 10 keV, since these are essentially free from the thermal component above 50 keV;
- micro-wave emission from 10 cm to mm wavelengths;
- XUV lines of high ionization potential, although the thermal component will also be important for these transitions;
- hard X-ray lines, in particular, the Fe lines around 1.9 Å;
- polarization of X-ray emission.

Such observations can provide evidence for the production of non-relativistic or very mildly relativistic electrons in flares through a fast acceleration process during the flash phase of flare development (before the flare maximum in soft X-rays and H α lines). However they cannot give any information on whether or not protons and relativistic electrons are also accelerated at the same time in the flare. In principle, there are three modes of detecting accelerated protons in the flare regions:

- white light flare occurrence, which, if present, coincides with the features listed above and which may be produced by protons of energy > 20 MeV bombarding the upper photosphere;
- neutrons produced by > 30 MeV protons and α -particles penetrating into the dense layers of the solar atmosphere;
- γ -rays and, in particular, γ -ray emission from C and N, as well as lines at 2.2 and 0.5 MeV, which are produced by neutron capture and positron annihilation, respectively;
- π^0 γ -rays in the 70-100 MeV continuum.

A comprehensive set of measurements of the characteristics of X-ray, γ -ray and neutron emission from the flaring and non-flaring Sun would give insight into the triggering mechanism of a flare, on the total energy content of a flare (in conjunction with other measurements), and into the acceleration, containment, and release of charged particles. The characteristics in the photon spectral range of 0.001 to 100 MeV that must be measured to achieve this objective are:

- the spectral energy distribution in the continuum and line radiation;

- the temporal history of the X-ray and prompt γ -ray emission, with a time resolution of better than 1 second;
- the polarization of the X-ray emission;
- the location of the X-ray emission in the solar atmosphere as a function of time and energy (this may be possible only for limb flares).

The needed characteristics for neutrons are flux, spectrum, and time history.

The measurements taken during flares will be of greater significance when compared with simultaneous radio spectral and spatial measurements and with solar particle measurements.

FUTURE SOLAR SPACE PROGRAMS

Pre-Shuttle Efforts

Balloon borne experiments will continue to be useful for studying some aspects of the photosphere but they are limited both by the weight carrying capacity and by the short time available during a flight. Further, they are not suitable for studies of the chromospheric and coronal spectrum in the wavelength region below $\approx 2000\text{\AA}$.

Rocket experiments can contribute to the solution of many of the problems associated with both the quiet atmosphere and long-lived active regions, and have done so with considerable success. They are limited eventually both by the weight carrying capacity of present rockets and the relatively short observing time available during a flight (i. e., ≈ 5 min). However, the short lead time of rocket experiments compared with satellite projects, is an advantage and any major satellite project should be supported by a rocket program as is the case in ATM, where scaled down experiments have been used to test instruments under development, and others will be used to calibrate and complement the ATM in flight.

The ATM experiments will add considerably in our understanding of the solar atmosphere and activity at an angular resolution of, typically, 5 arc sec. The OSO's I, J, K are designed to attain a resolution of about 1 arcsec. Short duration orbital experiments (such as could be made from a space lab) with observing times of ≈ 1 week would be valuable for most of the problems discussed above except those related to the long term development of active regions, where several months of observing is required. On a short duration

experiment, the suitability of flying an experiment to observe flares would depend on the likelihood of flares occurring, i. e., on the proximity of sunspot maximum.

The Shuttle

The Space Shuttle will present the long awaited opportunity to realize large scale solar experiments consisting of long-term, time-lapse observations of very high spatial resolution, performed for the first time simultaneously both in the visible, ultraviolet and X-ray region of the solar spectrum. The importance of such an integrated solar experiment as an overall approach towards a better understanding of the structure and dynamics of the solar atmosphere cannot be overemphasized.

GROUND-BASED ACTIVITIES

DISCUSSION

Solar Physics, more than any other branch of astronomy, integrates space and ground-based observations. Most solar physics investigations, particularly in solar activity, utilize both sources. Ground-based observations still provide the best data on many basic phenomena in the photosphere and chromosphere, particularly with regard to magnetic fields. On the other hand, space observations are preeminent for studies of the transition region, corona, and high energy phenomena. All these phenomena are simply different aspects of the same overall atmospheric configuration and data on all of them are needed for a complete understanding of the solar atmosphere. The OSO and ATM programs show how coordinated observations from space and the ground are an effective means of attacking solar problems.

The Shuttle Sortie permits observations with very high resolution and wide spectral range over a short period of time with but a few telescopes. Ground-based observations provide data from many telescopes over long periods but are limited in resolution and wavelength capability. Hence, the two are complementary. Comparison with ground-based data ties the Shuttle observations to many years of ground-based research. Ground-based observations provide the history and subsequent evolution of active regions under observation as well as developments during spacecraft night. A very important feature of ground-based observations is that, in providing many more examples of the same phenomena (Type III bursts, H α flares, etc.), they permit us to determine how "typical" our set of space observations are for the process studied.

Solar flares are the clearest example of the need for a wide range of data. Non-thermal electrons are detected by hard X-ray bursts (proportional to N_e or N_e^2) found in space, by microwave bursts (proportional to $N_e B$), by Type III bursts (proportional to escaping electrons), and by $\lambda 3835$ flashes (proportional to total energy). The physics of the event can only be understood with these and other data in hand. Coordinated observations are also necessary for solution of other problems such as the chromospheric network, sunspots, etc.

Ground based optical observatories will continue to contribute strongly to space solar astronomy. It is important that they be upgraded in preparation for the first Shuttle flights. In particular, their dispersing, detection, and image-processing equipment should be upgraded as required to take advantage of technical innovations. Examples of this ongoing improvement in that state of the art include video recording and storage techniques, solid-state detector arrays, Fourier and Hadamard spectroscopy, and laser applications. The measurement and interpretation of the Stokes parameters with ground-based facilities is an essential prerequisite for the use of a Stokesmeter behind the focus of a high resolution telescope to measure solar magnetic fields from space.

Existing radio telescopes, both in this country and abroad, are inadequate to support the solar program envisioned for the shuttle, particularly for flare studies during the next solar maximum. For example, measurements of the flux and polarization of centimetric and decimetric bursts can supply vital information on the non-thermal processes in solar flares. Most important is improvement in the sensitivity and time resolution of microwave monitoring telescopes. At present, small X-ray detectors are far more sensitive, yet the physical interpretation of X-ray observations requires the availability of correlative microwave data. Solar observations at frequencies above 15 GHz are presently quite limited and should be improved in order to produce information on the energy spectrum of synchrotron electrons.

In the high frequency radio range, the possibility exists of high resolution observations of high energy electrons in flares, comparable to what can be done with modulation collimators and, perhaps, even better. Existing radio interferometers can produce some information on this subject with one or two spatial frequencies, and their use should be encouraged. Also, studies of active regions with Shuttle-based experiments will require supporting ground-based instrumentation for high spatial resolution polarimetry in the millimetric wavelength region.

The propagation of solar material through the corona and solar wind can be observed with radio-heliographs in the 10-150 MHz range, and the physical state

can be inferred from multifrequency measurements of absolute radio flux, polarization, and time history, in conjunction with coronagraph, K-coronameter, and UV measurements from the ground and from space. The development of these techniques has just begun and holds great promise for contributing to solar and solar-terrestrial studies. This development should be vigorously pursued.

Laboratory measurements provide the atomic and physical data necessary for the quantitative interpretation of solar observations. These experiments include f-value and cross-section measurements, fundamental spectroscopy, and studies of the optical properties of crystals and surface. Such work is essential and quite cost-effective.

Finally, the fundamental importance of continuing to support a vigorous theoretical effort cannot be too strongly emphasized. It would be foolish in the extreme to spend large sums on collecting and reducing data with the most modern techniques available, only to fail to follow this up with a strong theoretical program which, alone, can lead to the final scientific goal: a profound understanding of the Sun and the relevant underlying physical processes at work there.

SELECTION AND RESPONSIBILITIES OF SCIENTISTS

This section addresses the subjects of the selection process and the responsibilities of scientists. Data analysis and interpretation are also discussed.

PHASES

We distinguish six program phases in Table 1, leading from conception of a mission to the end product of new knowledge.

GUIDING PRINCIPLES

- The goal is to gain significant new knowledge about the sun. The flight of hardware is one of several activities required to reach this goal.
- Compromise of the scientific objectives must be avoided, if possible, within program constraints.
- Conflicts of interest in the selection process are to be minimized.

Table 1

Program Phases of a
Space Experiment

- | | |
|------|--|
| I. | Establish disciplinary (solar physics) objectives for the mission. |
| II. | Define the experiment package needed to attain these objectives. |
| III. | Select the instrumentation. |
| IV. | Design and build the instrumentation. |
| V. | Operate the experiment package in space. |
| VI. | Analyze and interpret the data. |

- The best investigators must be selected for both hardware and operational phases.
- Successful construction and operation of individual instruments will be under the supervision of a single scientist who will assume complete responsibility for same.
- Limited flight opportunities make it imperative that some observing time on all larger instruments will be allocated to Guest Investigators.

SOME CONSEQUENCES

Implementation of the above principles implies the following consequences:

- Instrumentation that is sufficiently flexible to permit a wide variety of investigations should be operated as a national facility to insure broad and efficient use of the data. Technical and scientific descriptions must be provided to enable potential users of a facility to plan their own observing program, interface successfully with operations, and reduce, analyze, and interpret the resulting data.

- If required by the nature of the object of study, the coordination of observations with complementary instrumentation in space and on the ground is essential.
- Data analysis and interpretation are of paramount importance and must be adequately planned for and provided, lest the entire effort be wasted.
- There must be some form of open competition for all Program Phases I-VI. Individuals from institutions competing for places in a payload will not participate in the scientific review during the selection of this payload.

The implementation will be based on applicable NASA policy. This policy has been flexible and highly successful in the past. If it is changed in any way for the Shuttle era it should: remain flexible, be consistent with the guiding principles mentioned here, and permit operation in the light of the following procedures.

SELECTION PROCEDURE

We distinguish between three situations: the small (sounding rocket), very large (observatory) and intermediate (OSO) classes, see Table 2.

Phase III selection must not close the doors to instrumentation that attacks solar physics problems other than those envisioned in Phases I or II, so that imaginative new approaches are not discouraged.

A sounding rocket class experiment will continue to be conducted under the responsibility of a Principal Investigator rather than operated as a national facility. A large space observatory with a variety of instruments capable of multi-mode operation on a variety of targets can be envisioned only as a national facility. Intermediate scale projects warrant special arrangements, such as guest investigator programs.

In particular, for the intermediate class experiments, a single scientist will be responsible for the entire design and construction phases for any specific instrument. The scientists who are responsible for the elements of an intermediate class payload form a Science Steering Group which reviews the entire discipline payload. At any given time during the operational phase of an intermediate class payload the responsibility for the operation rests with a single scientist.

Table 2

Program Phases vs. Observatory Size

| Phase | Very Large | Intermediate | Small |
|---|---|--|--|
| I. Establish Objectives | Headquarters with advice from scientific community No conflict of interest arises. | | |
| II. Define package | AFO or Steering Group | AFO and proposals | Proposals |
| III. Select Instrumentation | Headquarters with advice from scientific community. Conflict of interest to be avoided. Advice through Ad Hoc Committee. | | Mail reviews |
| IV. Design and build Instrumentation | NASA under supervision of science steering group | Scientists subject to approval by NASA | Scientist within constraints and subject to required approvals |
| V. Operation in space | Science Steering or Users Group | Scientist or his User Group | Scientist |
| VI. Data analysis and Interpretation | Users | Scientist or his Users Group | Scientist |

For a very large (observatory or national facility) type of payload, it is proposed that the basic complement of instruments (telescope, magnetograph, etc.) be determined by a Scientific Steering Committee consisting of recognized scientists from the international community and working with the appropriate NASA Headquarters Program Office. After instruments are selected, the designated NASA Management Center, under the guidance of the Steering Committee and the Principal Scientists chosen to supervise construction of the individual instruments, would assume responsibility for management of the project and would be responsible for the procurement of the instruments (either from industry, the Principal Scientist, or a combination of these sources). Decisions on instrument definition, interface with auxiliaries, and procurement of instruments would all be made by the Steering Committee and the Principal Scientists.

To resolve difficulties which might arise from differences of opinion among members of the group consisting of the Steering Committee plus the Principal Scientists, one individual should be chosen to serve as "Head Scientist" for the entire national facility payload. This person would have final responsibility for the construction of this payload.

The determination of which instruments are large enough to be considered "National Facilities" will be made by the committee choosing the instruments. In general, we would expect this to apply to facilities with telescopes greater than one meter aperture, to very large and complex particle detectors, etc.

PROPOSED ROLE OF THE PRINCIPAL SCIENTIST

The category of Principal Scientist is introduced in connection with the very large observatory payload, to be operated as a national facility, as well as the intermediate class payload.

Recommendations Concerning the Principal Scientist

The following rules are recommended with regard to the Principal Scientist:

1. Every instrument will have a Principal Scientist (PS). An instrument may be a complete package such as a telescope, a spectrograph, or a magnetograph.
2. The PS is selected at the same time as "his" instrumentation on the basis of open solicitation and while avoiding conflicts of interest (Phase III).

3. The PS is responsible to NASA for the design, construction, and calibration of "his" instrumentation.
4. The PS has exclusive rights to a major portion of the observing time with "his" instrument in space in an intermediate class payload.
5. In a very large observatory payload, the PS will have substantial rights to observing time with "his" instrument. In either case, he has the responsibility to arrange for transfer of reduced data to the National Space Science Data Center (NSSDC) after an agreed upon time of no less than one year.
6. If he has exclusive rights to less than 100 percent of the observing time, the PS will produce a user's manual specifically to enable other users to understand the instrumentation, plan and execute a research program with it, and reduce the data to the point where they are interpretable in terms of flux versus direction, wavelength, and time.
7. The PS will assist NASA in the selection of users for the "open" portion of the observing time.

Recommendations Concerning National Facility Type of Payloads

For the national facility type of payloads the following is recommended:

1. A permanent staff should be developed to assume full operational management of the facility when it is ready for flight. This staff may overlap or even coincide with the Scientific Steering Committee plus the Principal Scientists group which guided the payload through its construction stage. The staff will have complete responsibility for the operation of the facility and the execution of its research program.
2. Selection of research programs and of the users who are not themselves PS's, should be the responsibility of a research committee of representatives from the solar physics community and the permanent staff. This committee will review research proposals to determine their compatibilities and will then judge their scientific worth. When approved, proposals will be given to the permanent staff, who will determine requirements for observation and related support. In order to ensure impartial consideration, the research committee will be composed of representatives from most of the major research centers and its membership will be changed periodically.

3. Selected users will be allowed exclusive use of their data for a specified period of time, after which the data would be made available to all other users.

All users are responsible to NASA for effective use of their assigned observing time, prompt analysis and interpretation of their data, and publication of their findings.

DATA ANALYSIS AND INTERPRETATION

The end-product of any successful scientific mission is the discovery and dissemination of new knowledge. A mission cannot be considered completed if it simply produces good raw data or even some sensational announcements based upon preliminary analysis. Publication of final results in an appropriate journal, after extensive analysis and interpretation, marks the successful completion of an investigation.

To ensure that research projects on the Shuttle reach this final goal, a number of functions, described below, must be planned for and funded. These functions are grouped into: the period following the flight when the principal investigator has priority over the data and the later period, when the data are open to any qualified investigator.

Period of PI and PS Priority

Sharing of Data—The principal investigators and scientists should be encouraged to collaborate with other guest scientists in the analysis of their data, even during the first two years following flight. Such collaborative efforts should be organized before flight.

Rapid Reduction of Raw Data—Analysis cannot begin before the raw data are available to the investigator. To reduce the time required for processing of telemetered data following flight, the Shuttle program must provide adequate staff and computing facilities. Quick-look facilities are especially valuable.

Extended Analysis—Funds to support analysis and interpretation of experimental data are a comparatively small but vital portion of the cost of the scientific program. They must be provided by NASA for a period commensurate with the value of the data, or by arrangement with other science funding agencies in this country or abroad. Foreign collaborating scientists can usually participate only if travel funds are adequate.

Period of Availability to Scientific Community

If qualified scientists, not originally associated with the Principal Investigator or Scientist, are to benefit from the data once they have been deposited in a data center, at least three requirements must be met:

1. The data must be adequately documented by the PI or PS, including calibration, instrument parameters, data formats, etc.
2. Lists of experiments, for which data are available through a data center, must be circulated widely and frequently.
3. Adequate staff and facilities must be made available at the centers for duplicating and distributing the data.

It would be extremely useful if travel funds for visiting the scientist who operated the flight experiment could be provided.

A FIRST SOLAR PHYSICS SHUTTLE PAYLOAD

OBJECTIVES

The general area of solar activity, flares, and flare associated phenomena was chosen for the first solar physics payload, to be flown as early as possible and as close as possible to the solar maximum of about February 1979.

The primary objective of the payload will be a problem-oriented approach to research in this area, using a complement of instruments rather than a single, large instrument. This is made necessary by the nature of the relevant solar phenomena, which are observable over a broad spectral range either simultaneously or during various phases of their development. For example, flares may be studied simultaneously with high energy and optical spectroscopy instrumentation; while the propagation of flare emissions is best observed in the far UV, white light coronagraphs and ground based radio telescopes, and radio detectors on spacecraft, in order of increasing distance from the Sun.

Secondary objectives include other areas of interest in solar physics. For example, the payload is chosen in such a way that the instruments can attack the primary problem area identified by the ESRO PASOL group, the study of the heating of the solar corona. This "quiet" Sun objective can be attained with the same instrumentation, through the use of special modes which can be incorporated readily through software changes, use of selectable slits in spectrometers, etc.

Other secondary objectives include studies of the earth's atmosphere through extinction of solar radiation. As envisioned, solar instrumentation would be

entirely sufficient to carry out this kind of work, while instrumentation designed specifically for extinction studies would be useless for the more demanding solar work.

Finally, solar instrumentation could be useful for other astronomical observations. As in the case of atmospheric instrumentation, the reverse (use of stellar instrumentation to look at the sun) is usually not feasible.

INSTRUMENTATION

High Energy

In recent years it has become clear that high energy particles play an important role in solar flares. Gamma-ray, X-ray, and radio emission are generated by processes involving high energy particles. The general nature of these processes can often be inferred directly from the presence and nature of the nuclear gamma-rays, the polarization of soft X-rays, and the spectral dependence of hard X-ray flux, along with other information. Flux measurements of these quantities, made with good spectral and time resolution, are essential. By determining these quantities simultaneously with radiation in the optical, UV, and XUV, taken with high spacial resolution in the flaring region, it should be possible to develop a comprehensive physical model for solar flares. The significant increase in payload weight and collecting area afforded by the Shuttle will permit the study of both large and small events with greatly increased spectral, time, and, where relevant, angular resolution.

The specific instruments in this general area are listed in Tables 3 and 4 for the coarsely pointed instruments, and in Table 5* for the soft X-ray instruments for the spectral range 1-100Å.

Fine Pointed Instruments

High energy phenomena on the sun can often be examined without the provision of a telescope, or the equivalent, because the flux from even a small flaring region is many of orders of magnitude brighter than from the quiet solar disk. However, one telescope for hard X-rays is required to determine the location of hard X-ray bursts with respect to the lower energy phenomena. The high

*Table 5 lists a possible complement of soft X-ray instruments. The wavelength ranges and other characteristics should not be taken literally, but as representative for a payload to meet X-ray observational requirements. Since a spectral resolving power of 10^5 is ultimately needed, the presently attainable values are indicated in brackets and shown in some cases as a range because of wavelength dependence.

Table 3
Candidates for Solar Instrumentation of a Dedicated Mission Coarse Pointed Instruments

| Instrument Type | MeV Energy Range | Required Pointing | Primary Measurement Objective | Weight, Power Volume, Telemetry |
|---|---|-------------------|------------------------------------|--|
| Proportional counters and/or cooled solid state detectors | 0.001-0.050 | $\sim 5^\circ$ | spectral (atomic line & continuum) | 90 kg, 10 w 0.13m ³ , 3 kbps |
| Actively shielded scintillators CsI and NaI | 0.030-0.600 | $\sim 5^\circ$ | spectral (continuum) | 450 kg, 20 w 1.0m ³ , 3 kbps |
| Actively shielded scintillators CsI and NaI | 0.300-10 | $\sim 5^\circ$ | spectral (continuum) | 900 kg, 20 w 1.0m ³ , 1 kbps |
| Actively shielded cooled solid state device | 0.100-10 | $\sim 5^\circ$ | spectral (nuclear line) | 700 kg, 20 w 0.64m ³ , 4 kbps |
| Li and Be scattering block polarimeters | 0.001-0.005 0.005-0.030 0.030-0.200 | 1° | continuum polarization | 100 kg, 15 w 0.34m ³ , 3 kbps |
| Bragg reflection crystal polarimeter/spectrometer | 0.001-0.010 | 1° | line and continuum polarization | 40 kg, 35 w 0.13m ³ , 1 kbps |
| Neutron sensitive scintillators | 1-100 MeV | Coarse | solar neutrons | 230 kg, 25 w 0.8m ³ , 1.5 kbps |
| Spark Chamber | ≥ 100 MeV | $1/2^\circ$ | high energy photons | 2500 kg, 36 w 100m ³ , 10 ⁵ bps |

Table 4

Coarse Pointed (CP) Payload Element Data

| Payload Element | Energy Range | Resolution Energy (Spectral) | Temporal Resolution | Data Rate | Power Avg/Peak Watts | Weight | Size | Pointing Acc/Stab | Temp. | Orbit |
|---|-----------------|---------------------------------------|---------------------|-----------|----------------------|---------|-----------------------------------|-------------------|----------------|----------------|
| 1. Solid State Flare Detector | 1 to 50 KeV | 20% 2% | 0.1 sec | 3 kbps | 20/20 | 90 kg | 0.5 x 0.5 x 0.5 m ³ | ±1°/±1° | 25°±10°C | * |
| 2. X-Ray Burst Detector | 0.03 to 0.6 MeV | 20% | 0.1 sec | 3 kbps | 20/20 | 450 kg | 1 x 1 x 1 m ³ | ±1°/±5° | -10°C to +30°C | 322 km @±32° |
| 3. X-Ray & Gamma-Ray Spectrometer | 0.3 to >10 MeV | 15% @300 KeV 5% @10 MeV | 0.1 sec | 1 kbps | 20/20 | 900 kg | 1 m dia x 1 m | ±1°/±5° | -10°C to +30°C | 322 km @±32° |
| 4. Gamma-Ray Spectrometer | 0.1 to 10 MeV | E/ΔE~10 ² -10 ³ | 1.0 sec | 4 kbps | 20/20 | 700 kg | 0.8 x 0.8 x 1 m ³ | ±1°/±1° | -10°C to +50°C | ≤10° |
| 5. Solar X-Ray A Polarimeter | 1 to 200 KeV | ~100% | 10.0 sec | 3 kbps | 10/15 | 100 kg | 0.68 x 0.68 x 0.68 m ³ | ±1°/±1° | 25°±20°C | 480 km @±35° |
| 5. Bragg Reflection B Polarimeter | 1 to 10 KeV | E/ΔE~10 ³ in Spectral Mode | 10.0 sec | 1 kbps | 5/35 | 40 kg | 0.5 x 0.5 x 0.5 m ³ | ±1°/±1° | 25°±10°C | |
| 6. Solar Neutron A Experiment | 2 to 100 MeV | 20% | | | 22/22 | 230 kg | 1.3 x 1 x 1 m ³ | ±5°/±5° | 0°C to 30°C | <322 @ Equator |
| 6. High Energy B Gamma-Ray & Neutron Detector | >10 MeV | | | 0.5 kbps | 5/5 | 100 kg | 0.4 x 0.4 x 0.4 m ³ | ±1°/±1° | -10°C to +50°C | ≤10° |
| 7. Gamma-Ray Detector (Spark Chamber) | >100 MeV | | | 100 kbps | 100/~100 | 2300 kg | 2.7 x 2.7 x 2.7 m ³ | ±0.5°/±0.5° | 0°C to 25°C | * |

*Stay out of radiation belts

Table 5
Requirements for Solar X-ray Instrumentation 1-100 Å

| Instrument | Wavelength Range | Spectral Resolving Power $\lambda/\Delta\lambda$ | Spatial Resolution Arc Sec | Data Rate (BPS) | Weight (kg) | Size (Meters) |
|---|------------------|--|----------------------------|---|-------------|-------------------|
| Grid Collimator-Photometer* (for source acquisition) | 1-8 Å † | (3-7) | 2 | Count Mode 10^2 Spectral Mode 10^3 | 20 | 2.0 x 0.25 x 0.25 |
| Telescope with focal plane Spectrometer (Gratings) | 10-100 Å | 10^5 (10^3) | 2 | Video 10^7 Spectral 10^4 | 250 | 0.5 x 0.5 x 2.5 |
| Telescope with focal plane Spectrometer (Crystals) | 1-10 Å | 10^5 ($10^4 - 10^5$) | 2 | Video 10^7 Spectral 10^4 | 250 | 0.5 x 0.5 x 3.5 |
| Collimated Spectrometer (Crystals) | 1-6 Å 3-10 Å | ($10^4 - 10^5$) (10^4) | 2 | 10^4 | 150 | 0.5 x 0.5 x 3.0 |
| Scattering-Block Polarimeter | <1-3 Å | (3-5) | Whole sun | 10^4 | 680 | 1.0 x 1.0 x 2.0 |
| Crystal-Reflection Polarimeter | 1.5-10 Å | (10^3 **) | 100 | 10^4 | 40 | 0.5 x 0.5 x 0.75 |

*Simple photometer attached for signalling events.

**Higher resolving power possible but not desirable for this instrument.

†1-8 Å is a good band for active regions. To locate hard x-ray positions in flares a variety of choices exists.

energy telescope is an Oda collimator followed by a detector with pulse height analysis for energy discrimination.

To get at the physics of solar flare related phenomena, it is necessary to determine the physical conditions in the flaring region and the corona above. This is important in the flare phase as well as before and after a flare, both for a determination of the flare buildup and the energy release mechanisms and, additionally, for the tracking of flare debris, such as plasma, shock waves, and high energy particles.

A coronagraph and an X-ray telescope are required to determine densities and magnetic fields in the corona. Collimated XUV and soft X-ray spectroscopy can be used to determine temperatures and densities of the hot material. Chromospheric effects are best studied by visible and UV spectroscopy with high spectral and angular resolution.

Angular resolution of about one arc second or better is required in the entire range from soft X-rays to the ultraviolet. Spectral resolution of about 100,000 is required for chromospheric and some coronal work. For other coronal studies the requirement is relaxed by about one order of magnitude. Even this lower requirement is technically demanding because of the nature of spectroscopic instrumentation and the substantially lower solar flux in that range.

The instruments in Tables 6 and 7A and 7B show how the Working Group feels the requirements can be met most effectively. A further discussion of some of the more detailed observational requirements appears in Part B of this report.

There are a number of independent indications that still higher angular resolution approaching 0.1 arc seconds will be required for the solution of a number of solar physics problems. For example, the scale height in the chromosphere is of that order as seen from the earth near the solar limb. Occultation measurements of an X-ray flare from OSO-5 showed structure of the order of 0.5 arc seconds or less. Hard X-ray bursts exhibit a time structure which implies small spatial structure in the emitting region. Occasional glimpses of the Sun at higher angular resolution than normally obtainable show sub-arc second solar structures of significance for mass and energy transport in the photosphere, the chromosphere, and in sunspots (from data collected with balloons and high resolution ground-based telescopes). Indirect evidence is equally suggestive of the need for sub-arc second angular resolution. An example is the observation of a 90 degree change in the direction of the transverse photospheric magnetic field near a sunspot over a distance of one resolution element (about 2 arc seconds) in a magnetogram.

Table 6
Candidates for Solar Instrumentation of a Dedicated Mission Fine-Pointed Instruments

| Instrument | Wavelength Range | Spectral Resolution $\lambda/\Delta\lambda$ | Spatial Resolution (arc sec) | Data Rate (bps) | Weight (kg) | Size (Meters) ³ / Power (Watts) |
|--|----------------------------|---|------------------------------|-----------------|-----------------------|--|
| Photoheliograph | 1000 to 11000Å | 5×10^5 | 0.2 | 10^7 (video) | 900 with spectrograph | 27/? |
| Ultraviolet Spectroheliograph (normal incidence) | 300 to 2000Å | 3×10^4 | 1.0 | 10^5 | 270 | 1.5/120 |
| EUV Spectroheliograph (grazing incidence) | 100 to 600Å | 1×10^4 | 1 to 2 | 10^4 | 150 | 0.15/20 |
| Soft X-ray Telescope/Spectrograph | 10 to 100Å | 10^4 to 10^3 | 2 to 5 | 10^4 | 250 | 3/100 |
| Soft X-ray Spectrometer | 1 to 10Å | 10^5 to 10^4 | 2 | 10^4 | 150 | 1/30 |
| Acquisition Instrument (Multigrid Collimator) | 1 to 8Å or other selection | ~ 5 | 2 | 2×10^2 | 30 | 0.13/15 |
| Acquisition Instrument (Oda Collimator) | 20 to 200KeV | ~ 10 | 2 | 5×10^2 | 50 | 0.25/15 |

Table 7A
Fine-Pointed (FP) Payload Element Data

| Payload Element | Orbit | Absolute | Drift | Jitter | Off Set Pointing | Sensors | FOV |
|--|----------------|---------------|---|--|-----------------------|---------------------|----------|
| 1. Externally Occulted Coronagraph | Sun Sync Polar | 20 sec | ± 1 sec/min | | Internal | Film or Vidicon | |
| 2A. 65 Centimeter Photoheliograph | 322 km @30° | 10 sec/50 min | ± 1 sec/sec P, Y ± 4 sec/sec R | < 0.05 sec/sec | ± 1 sec | | |
| 2B. 100 Centimeter Photoheliograph | " | " | ± 0.5 min R | 1 sec 0.01 sec/rms | ± 1 sec | Film & Vidicon | |
| 3. U.V. Spectrograph | " | ± 5 sec | ± 1 sec/15 min P, Y ± 3 min/15 min R | ± 0.25 sec/min | | Film & Vidicon | |
| 4. E.U.V. Spectro-heliometer | 500 km @30° | ± 5 sec | ± 1 sec/15 min P, Y ± 3 min/15 min R | P & Y ± 0.1 sec/15 min R ± 17 sec/15 min | P & Y ± 20 min | PMT's | |
| 5. Spectrometer/ Spectroheliograph | @33° | ± 5 sec | 1 sec/hr | ± 0.3 sec/min | | | |
| 6. Soft X-ray Telescope/Spectrograph | " | 10 sec | ± 1 sec/15 min | ± 1 sec | P & Y ± 20 min | Film/Photo-electric | Variable |
| 7A. Soft X-Ray Spectrometer/ Spectroheliograph | " | 10 sec | " | " | " | Photoelectric | 2 sec |
| 7B. Grid Collimator Acquisition Photometer | " | 10 sec | " | " | " | " | 2 sec |
| 8. Modulation Collimator | " | 10 sec | 1 sec/min | " | " | " | 0.5° |

Table 7B
Fine-Pointed (FP) Payload Element Data

| Payload Element | Spectral Range Å | Spectral Resolution $\lambda/\Delta\lambda$ | Spatial Resolution | Data Rate | Power (Watts) Avg/Peak | Size | Weight | Temperature Range |
|---|----------------------|--|---|---------------------|------------------------|---------------------------------|--------|-------------------|
| 1. Externally Occulted Coronagraph | 4000 to 7000 | 20 | 4 sec | 1Mbps | 40/100 | 0.61 x 0.61 x 4.6m ³ | 204kg | 70°±5°F |
| 2A. 65 Centimeter Telescope/Spectrograph | 1200 to 10000 | 5 x 10 ⁵ | * | * 8Mbps | * | 1 x 1.5 x 4m ³ | ~900kg | 10°±3°F |
| 2B. 100 Centimeter Telescope/Spectrograph | 1200 to 11000 | *5 x 10 ⁵ | * | 12Mbps | * | 1.5 x 3 x 6m ³ | *1200 | 10°±3°F |
| 3. U.V. Spectrograph (with telescope) | 1000 to 2200 | 3 x 10 ⁴ | 0.5 sec | TV link 2.5 Kbps | 50/100 | 0.4 x 0.4 x 3.6m ³ | 250kg | 20°±10°C |
| 4. E.U.V. Spectro-heliometer | 280 to 1700 | 3 x 10 ⁴ | 30 sec @ 0.5° 5 sec @ 5' 1 sec @ 1' | 107Kbps | 100/120 | 0.66 x 0.61 x 3.7m ³ | 270kg | 70°±5°F |
| 5. Spectrometer/Spectroheliograph | 100 to 600 | 1 x 10 ⁴ | 2.5 sec ² | 1 Kbps | 15/20 | 0.2 x 0.4 x 2m ³ | 150kg | 70°±10°F |
| 6. Soft X-ray Telescope/Spectrograph | 10 to 100 | 10 ⁴ -10 ⁵ | 1 sec | 20Kbps | 50/60 | 3m x 0.5m ² | 250kg | 70°±10°F |
| 7A. Soft X-ray Spectrometer/Spectroheliograph | 1 to 25 | >10 ⁴ @ 6Å 5 x 10 ³ @ 10Å <10 ³ @ 25Å | 2 sec | 20Kbps | 60/100 | 1.5 x 1.5 x 4m ³ | 270kg | 70°±10°F |
| 7B. Grid Collimator Acquisition Photometer | 1 to 8 or selectable | 5 | 2 sec | 200bps | 5/15 | 1 x 0.5 x 0.25m ³ | 30kg | 70°±10°F |
| 8. Modulation Collimator | 20 to 200KeV | 5-10 | 2 sec | 500bps | 10/15 | 0.2 x 0.4 x 3.1m ³ | 50kg | -40°C to +40°C |

*Variable -- See Payload Element Data Sheet

A photoheliograph is the likely first instrument to explore this new frontier of very high angular resolution because the solar flux in the visible and near UV is higher than anywhere else in the spectrum. Consequently, in the near future, we can expect to simultaneously obtain for this spectral region the combined high angular, spectral, and time resolution needed to crack a number of important problems of atmospheric structure and dynamics. A goal of 0.1 arc sec angular resolution in the $H\alpha$ line would require a 1.5 meter telescope. Since it would be quite expensive to build this instrument now, a logical next step beyond the 30 cm spectrostratoscope balloon instrument would be a telescope of roughly twice that aperture. Such an instrument is likely to be the most cost-effective next step because of extensive experience with a 65 cm functional verification unit which has been built and tested and is currently being installed at a ground-based observatory. This instrument will be quite demanding in stability, weight, size, and data rate and is included in the first payload under the assumption that it can be accommodated.

A few technical problems can be anticipated in operating these fine pointing instruments. While annoying, these should not be insurmountable. For example, since it seems necessary to use line intensities in both the 40-200 Å and 300-1200 Å ranges to determine electron temperatures from a given ion radiating in both these ranges, careful co-alignment of the two instruments will be necessary. By identifying these kinds of technical requirements, determined by scientific objectives, added expense and last minute frustration can be kept to a minimum.

Another such problem could be the one involving the spectral resolution required to resolve lines at short wavelengths (at least $\Delta\lambda = 0.2\text{Å}$ at 170Å and $\Delta\lambda = 0.5\text{Å}$ at 500Å). This can now easily be done photographically. However, photoelectric techniques are preferred if the required resolution can be obtained. Further development of the relevant technology is needed here.

FEASIBILITY

The instrumentation described (see "Payload Element Data Sheets," Tables 4, 5, 7A and 7B) is within the predictable state of the art at specific institutions in this country and abroad. However, most of it cannot be procured on the open market or without the day to day involvement of the few experts in each field who have sufficient experience and know-how to make the instrumentation perform meaningful scientific measurements.

Some of the instrumentation is in existence today in the form of functional verification units, balloon and sounding rocket payloads, and flight rated or spare spacecraft instrumentation. For example, some ATM flight spare experiments

can be used if modifications such as variable slits, slit jaw cameras, and different detectors are included.

INTEGRATION

To make a reasonable package, the telescopes must be co-aligned and have adequate registration of pointing targets. Slit-jaw photographs on spectrometers and visible light photographs taken through X-ray collimators are required to provide positive registration.

IMPACT ON THE SHUTTLE

The solar payload imposes several requirements on the Shuttle and is ideally suited for an early assessment of its capabilities to support science. For example, the sensitivity to contamination ranges from virtually none (most of the high energy instrumentation) to severe (coronagraphs for dust, UV instrumentation for vapors). Stability requirements range from virtually none (about one degree) for most of the high energy instrumentation to most demanding (0.1 arc seconds over seconds to minutes) for the high resolution visible telescope. Data rates range from low for most of the high energy instrumentation to very high for the high resolution visible telescope. Platform requirements range from quite uncritical (hard mounting acceptable) for most high energy experiments to critical for the high resolution visible telescope.

IMPACT ON OTHER DISCIPLINES

Solar instrumentation can be used for the study of other celestial objects and the earth's atmosphere. The reverse, use of non-solar astronomical instrumentation or earth's atmospheric facilities for solar work, is usually not feasible, as already noted.

Other areas where solar instrumentation would have application are as follows:

- Solar instrumentation can be used to observe bright stars or X-ray objects without any modification. This will not be as efficient as the use of instrumentation specifically optimized for this non-solar work, but will represent an important "fringe benefit," namely, the use of solar instrumentation during satellite night. On the other hand, the non-solar astronomy instruments designed or built so far do not tolerate pointing at the sun and are useless for solar observations.

- Solar instrumentation in earth orbit has historically been used for extinction measurements in the earth's atmosphere. The finite size of the solar disk implies averaging over different layers in the earth's atmosphere and has rendered these measurements of limited use. Studies of the earth's atmosphere, especially of the abundances of pollutants and other minor constituents and of ozone, require: angular resolution to discriminate the different layers in the earth's atmosphere; a stable platform to avoid smearing or source fluctuations; spectral resolution to identify different chemical constituents; and a broad spectral coverage from the XUV to the visible or beyond to gain access to different constituents and different layers of the atmosphere. These requirements translate into a set of instruments which are of exactly the same type as the instruments required for solar observations in the same spectral range. While the solar instrumentation can satisfy the requirements of earth atmospheric studies simply by the use of a long and somewhat wider field of view, the reverse is not true. Instruments designed for atmospheric work have an angular resolution which is too coarse for solar work by a factor of 10 to 100.

SUMMARY OF FIRST SOLAR PHYSICS SHUTTLE PAYLOAD

A first solar physics payload has been identified to provide a coordinated attack on an outstanding solar problem area: i. e., solar activity, flares, and flare associated phenomena. This payload will do so in a timely manner, using the Shuttle at a time of maximum solar activity. The same payload can be used to attack other major solar problems, such as the energy and mass transfer in the solar atmosphere related to chromospheric and coronal heating. It can also contribute in an important way to other disciplines, both through use of the solar instrumentation for direct observations of the earth and celestial objects, and through the scientific impact of new knowledge in solar physics on other disciplines in physics and astronomy. This payload has the potential to evolve towards a Large Solar Observatory of the future.

PART B
TECHNOLOGY
AND THE ROLE OF MAN

OBSERVATIONAL REQUIREMENTS

GENERAL REQUIREMENTS

Space flight solar instrumentation must meet progressively higher performance standards in spatial resolution (0.1 sec), spectral resolution ($10^4 - 10^5$), and, in some cases, time resolution of 1.0 sec or better. Spectral coverage ranges from gamma-rays and X-rays up through the infrared. Simultaneous observations at selected wavelengths within this spectral range are required. A new class of space flight instrumentation including magnetographs and photoelectric techniques for high resolution matrix coverage, must be developed.

Impacts of these general requirements include:

- Co-Alignment of Instruments — In advanced instrumentation, it is difficult to realize simultaneous observations in significantly different spectral regions because of the variety of optical designs required to efficiently collect energy for the sensors (crystal spectrometers, magnetographs, Rowland circle and Ebert-Fastie spectrometer mounts, coronagraphs, etc.) used in solar observations.

The significance of this co-alignment requirement may be considered as follows. When a fore-optical system such as a two mirror telescope is used in conjunction with a spectrometer or image recorder, one is primarily required to maintain the relative alignment of the mirrors. Even though a small residual misalignment may be experienced between the sensor and fore-optics, the effective boresight may be compensated for by calibration of the pointing off-set in orbit. On the other hand, two instruments, each instrument consisting of a set of fore-optics and sensors, is far more complex. Correction of internal fore-optical misalignments and calibration of boresight off-set between instruments is necessary but may not be sufficient. The severe spatial resolution requirements, 0.1 arc second, and limits on structural engineering in building static structures (that is, the limit of maintaining a fixed positional accuracy through launch and a varying thermal environment) indicate that adjustment of the total instrument package (boresighting) in orbit must be considered as an additional design requirement.

- Common Object Viewing — Even though co-alignment techniques may be incorporated to achieve coincidence of instrumental boresights, it is not yet clear in what way the different sensors will be used to assure that the same object is being viewed by the separate instruments. For instance, are X-rays emitted from the same spatial region (to within 0.1 arc second

or better) as ultraviolet flux, and are magnetic fields also to be associated with this point in space? This may be the very information that the observations were to determine.

- Significant Object Location — Techniques must be developed to predetermine and/or quickly determine the location of solar features of interest. This is particularly important when the solar feature has a short lifetime. How does one quickly locate on the solar disc a very small object (0.1 arc second) which has a short lifetime or significant decay history, before the object disappears or has proceeded significantly through its rise or decay lifetime?
- Calibration of Instruments — This is an extensive requirement covering mechanical and optical calibration, including absolute photometric calibration. A great deal of laboratory research and development will be needed to solve instrumental calibration problems. In addition, the problems of calibrating space magnetographs must be investigated.

The importance of absolute calibrations cannot be overestimated, especially in the short wavelength range below 1300Å, where the efficiency of optics and detectors seem to fluctuate drastically.

Absolute calibration in the UV photometry of the Sun will contribute to a better understanding of the physics of the Sun, but will also be of value to atmospheric physicists and aeronomists in collecting fundamental data for learning how the earth's atmosphere reacts to radiative excitation by the solar UV.

The Shuttle should be able to carry a simple calibration facility with standard sources and detectors covering the whole spectral range from the X-rays to the IR.

It is not impossible to imagine that in the future of the Shuttle, synchrotron sources will be placed into orbit for calibration purposes in the far UV. This is of course only imaginable within the concept of the Shuttle as a laboratory in space.

REQUIREMENTS IN DIFFERENT WAVELENGTH REGIMES

Infrared

Solar astronomy stands to profit by a number of infrared observations that can be made only from above the tropopause. Many could be carried out adequately

and relatively inexpensively from balloons or high altitude aircraft; however, observations from the Shuttle have some desirable attributes. In particular, the long observation time available, and the possibility of co-ordination with observations in other spectral regions, are attractive. A distinct drawback is the lack of high spatial resolution, predicated by the moderate apertures of currently foreseeable Shuttle instruments. A one meter telescope can produce a diffraction-limited image of one arc sec at 5μ , but only 1 arc min at 300μ . There is no problem, in principle, with using part of the beam from a white-light or near UV instrument, and if an all-reflecting system in the one meter range is planned, serious consideration should be given to its potential infrared uses.

Some important infrared observations that could be carried out with an aperture in the one meter class include:

1. Continuum Observations

The infrared opacity in the range 1.6μ to 1000μ increases smoothly with wavelength, and absolute photometry throughout that range should give reliable information on the height distribution of the temperature minimum. Absolute photometry practically requires being above all terrestrial absorbers, and makes such observations from the ground or even from the NASA aircraft exceedingly difficult. However, absolute photometry could be quite reliable from the Shuttle, provided contamination of the telescope equipment is negligible. Observations would be made at disk center, and would require only modest spatial resolution.

Center-to-limb variations at continuum wavelengths between 1.6μ and 1000μ would be quite useful with a one meter aperture. Image restoration techniques should abate the increasingly serious diffraction problem longward of about 20μ .

Recent calculations have suggested that solar flares may produce observable infrared continuum emission both from thermal emission and from non-thermal synchrotron radiation. If ground-based data show such emission to be observable, correlated space observations of flares in the infrared, visible, UV, and X-ray regions would be very useful.

2. High Resolution Spectroscopy

While airborne spectrometers have made a few solar observations in the region 1μ to 1000μ , a large aperture above altitudes accessible by presently-planned aircraft telescopes is ultimately needed. The region

1 - 20 μ should be thoroughly mapped in order to fill in the blanks left in ground-based or airborne studies by terrestrial absorption. The spatial resolution of a one meter aperture is needed to permit observations from center to limb and in sunspots and faculae. The solar spectrum from 10 μ to 1000 μ is almost totally unexplored at present and merits complete mapping. In addition to a few atomic lines, many pure rotation lines of diatomic molecules should occur in this region. The spectrum of sunspots is of particular importance, since most molecules (with the exception of CO) will probably be of sunspots at wavelengths up to about 50 - 100 μ .

High quantum-number transitions in ions such as O VII and Fe XV have been predicted to produce observable far infrared lines, although recent calculations indicate the lines to be very weak. If observable, such lines would be of great importance. Infrared atomic lines should have large sensitivity to magnetic fields (since the Zeeman shift $\Delta\lambda/\lambda$ varies as $g\lambda$ where g is the Lande factor), so if far infrared coronal lines are found, they may provide a much-needed way of measuring coronal fields directly.

It is very desirable that high-resolution infrared spectroscopy of the solar disk and corona continue from aircraft and balloon altitudes so that the above possibilities can be evaluated as soon as possible.

In summary, it is felt that infrared solar astronomy from the Shuttle should utilize large apertures to attain as much spatial resolution as possible, and it is recommended that if a large aperture all-reflecting visible or UV telescope is constructed, provision be made for infrared use.

Visible

Before the advent of space observations, this was the principal realm of solar research. Although these observations may be carried out from the ground, a space platform offers great new opportunities in this fundamental spectral region. The principal gains of space observations are higher spatial resolution and avoidance of the absorption and scattering by the atmosphere.

In the optical range, space telescopes will allow the full use of diffraction-limited optics for the first time, permitting us to improve on the present limit of 0.5 arc sec by a factor of three with a 65 cm instrument and 6 for a 1.5 meter telescope. In the past, each improvement in resolution has revealed dramatic new phenomena. During the last year, high resolution observations with the new telescopes that occasionally provide 0.5 arc sec have revealed the fine filigree structure at the base of the chromospheric network, running penumbral (Stein) waves, fast flashes of light produced by hard electrons impacting the surface from flares, and other totally unexpected phenomena. Yet, these telescopes just barely reach 0.5 arc

sec on occasion with high contrast features. A space telescope will permit sequential observations of lower contrast features. It will permit us to investigate the solar granulation in detail for the first time, and to determine the lifetime of spicules and other elements of the quiet chromosphere. With the discovery of umbral flashes and running penumbral waves, sunspots have become a new center of interest. These phenomena are just at the limit of present instruments, and should be accessible to detailed study from space.

The visible emissions from solar flares are another key object. High resolution observations of chromospheric structure coordinated with magnetograph measurements give a good picture of the magnetic stresses involved in flares, but the field details are still smaller than can be detected from the ground. There has been a big gain in our understanding of flares from the recent advances in high resolution and we may project further gains from still higher resolution.

It is important to remember that high resolution visual telescopes may be used in space down to the Lyman alpha wavelength. Particularly important are observations in the longest wavelength transition zone lines, C IV at 1550Å and Si IV at 1400Å. These lines offer the best chance to observe C IV the transition zone with extremely high spatial resolution.

The instrumental requirements in the visible and near UV may be summarized as follows:

1. A large aperture telescope in the 65 cm class with suitable coatings for observations in the range 1000 - 11000Å. Optical resolution diffraction limited at 5000Å and as high as possible at 1400Å. Special efforts should be made to produce fine polish for the UV. Pointing requirements: 0.05 arc sec rms jitter, 10 arc sec absolute, 0.2 arc sec relative.
2. Auxiliary instrumentation as follows, with different auxiliaries to be used on different sorties: H α filter and camera; universal birefringent filter; filter video magnetograph; white light camera with miscellaneous filter such as 3835Å Chapman type; UV filters for 1400 and 1550Å, 10Å wide. Spectrograph with resolving power 500,000, slit jaw camera and silicon diode array of at least 512 diodes. Near UV spectrograph.

Special efforts should be made to develop the narrow band UV filters and to produce extremely good surfaces and coatings. At 1500Å, the resolution of the telescope would be three times greater than at 5000Å, but normally we cannot realize this because $\lambda/150$ surfaces at 5000Å are required. It may be necessary to provide special cooling for the diode array.

Observations of the visible electron-scattered light from the corona provide information on the coronal electron-density. Correlation with measurements of the soft X-ray emission from the corona provides unambiguous specification of the temperature and density of the corona as observed at the limb.

A better understanding of the inner corona will allow determination of the solar wind lower boundary conditions, elucidate the mechanisms of meter-wavelength radio emission from the corona, and shed light on the process which transfers mechanical energy from the chromosphere to the corona.

An externally occulted, white light coronagraph, used in conjunction with X-ray instrumentation, would be useful for investigating these problems. Some properties of a white light coronagraph designed with a capability to follow localized phenomena would include: a field of view extending from as close to the solar limb as possible out to 13 solar radii; and an angular resolution of 0.1 arc second.

UV and XUV

The UV and XUV ranges, from a few thousand to about a hundred Angstroms, provide the optical wavelengths necessary to probe the solar atmosphere from the high photosphere through the temperature minimum and upward through the chromosphere and transition region into the corona. Thus the whole temperature range and structure from several thousand to several million degrees is investigated by means of observations in these two wavelength regions. It is precisely in this range of heights that the energy losses from the chromosphere and corona are balanced by a mechanical energy input, to form the rising temperature structure which has yet to be understood in detail. Observations in this wavelength range can be used to calculate electron densities, ion abundances, velocities, temperatures, and departures from thermodynamic equilibrium. It is therefore essential to make observations in these wavelength regions to understand a broad range of solar phenomena from the oscillations and structure in the quiet network to the structure of active regions and the production processes for flares. The whole problem of the interaction of the solar plasma with magnetic fields (stationary, quiescent, and dynamic) requires observation in the UV and XUV regions.

The solar chromosphere, transition region, and corona include some significant structures with a scale smaller than resolvable with either the OSO or ATM instruments. It is important that resolution down to one arc second in the far UV be achieved to resolve many of the more interesting structures in the quiet atmosphere, sunspots, prominences and filaments, active regions, and flares. The spatial resolution must be achieved with sufficient time resolution to follow temporal development of the structure, in a sufficient number of lines formed at

different heights to permit construction of a density-temperature model of the region studied. High spectral resolution will be necessary for this latter task, as well as to permit accurate velocity field determinations.

The instruments which span this spectral range appear mainly in Tables 6, 7, and 8 of Part A.

The Frascati meeting of the ESRO PASOL group considered the following instrument, proposed by P. Lemaire, for studying both the UV and visible spectral range. Careful examination of the features reveals that it would be the type of instrument suitable for mating with the photoheliograph telescope described in Part A. Specifications include:

- Spectral range: $1200\text{\AA} - 7000\text{\AA}$
- Spectral resolution: 0.01\AA
- Spatial resolution (max./average): $0.12 \text{ arc sec}/0.25 \text{ arc sec}$
- Data Rate: $\sim 10^7$ bps
- Power (peak/average): 1000 watts/400 watts
- Size: $2 \times 2 \times 4.5 \text{ M}^3$
- Weight: 800 kg
- Temperature range: $20^\circ \pm 10^\circ \text{ C}$

Soft X-ray

During the 1972-85 period, solar physics requirements in the soft X-ray regime (1 to 100\AA) will be crucially important. The primary emissions from flares, active regions, and the quiet corona fall in this spectral range; line emissions completely dominate in the portion from 20\AA to 100\AA , while the continuum becomes more important at shorter wavelengths around 1\AA to 10\AA and dominates below 1.5\AA . Line Doppler width measurements will require a resolving power $\lambda/\Delta\lambda = 10^4$. Detailed line profile studies require even higher resolving power up to $\lambda/\Delta\lambda = 10^5$. Below 10\AA it is possible to achieve resolving powers of 10^4 , and in special cases up to 10^5 , by careful selection and processing of crystals. Above 10\AA there is little hope of achieving resolving powers greater than 10^3 with crystals, because of limitations imposed by crystal physics, independent of technological constraints. Therefore, the development of plane and concave

grating instruments for the 10\AA to 100\AA region must have high priority in order for solar X-ray spectroscopy to overcome the deficit in resolving power capability compared to other spectral bands.

Meanwhile we must state the soft X-ray instrumentation requirements of solar physics in the Shuttle era in terms of the observations needed. Morphological studies will continue to have a high priority, requiring X-ray telescopes with a spatial resolution of one arc second. Fortunately, these telescopes can also be used to improve the sensitivity and spatial resolution of soft X-ray spectrographs. The focal plane camera used for broadband photographs may be replaced by a focal plane spectrograph.

For the requisite line profile observations in the 10\AA to 100\AA range a combination of telescope and spectrometer will be essential. Since the spatial resolution characteristically becomes much worse a few arc minutes off the telescope axis, the spectrometer entrance aperture should be on axis at the focal plane and the entire system should be offset pointed to obtain spectroheliograms and spectrograms of highest resolution. As noted above, the spectrometers should have resolving power up to 10^5 . Simple photographic mode operation with the telescopes will require video data rate of 10^7 bps, while the spectrometer modes should not require more than 10^4 bps. However, the spectrometer mode duty cycle (~ 50 percent) will be much higher than the photographic mode. Accumulation of $\sim 3 \times 10^8$ bits per orbit should be accommodated. This instrumentation would observe primarily solar features and events that do not change in times of seconds, hence a storage of data rather than continuous transmission would be acceptable.

For line profile and continuum studies in the 1\AA to 10\AA range, the telescope and spectrometer combination is still the optimum instrumentation. However, design criteria impose the need for a separate telescope design, and, as noted above, crystal spectrometers will replace the grating instruments at the focal plane. Requirements for bit rates, spatial resolution, and spectral resolution are the same as for the range longer than 10\AA .

At the very shortest wavelengths, below 3\AA , telescopes become less effective and one then needs X-ray spectrometer-spectroheliographs consisting of very fine collimators that limit the X-ray beam angular divergence relative to the dispersing crystals. The instrument technology in this range is especially easy to handle. On the other hand, radiation from the sun in this range is strong only during rapid, energetic events. In order to locate the event immediately and keep up with the rapid evolution in spatial and spectral character, several requirements arise. First one has to locate the region and make all relevant instruments point to the same location on the sun within one arc second. Acquisition

should occur within 10 - 30 seconds of detection, which implies a fast reaction rate for the pointing mechanism. Event durations range from more than an hour to less than a minute.

Another type of instrument required for short wavelength ($<10\text{\AA}$) studies is the X-ray polarimeter. There are two types, both of which should be incorporated in a flare dedicated payload. A polarimeter based on Thomson scattering from blocks of low Z material utilizes a broad band of X-radiation and can view the whole Sun. One based on the angular dependence of crystal reflection is well suited to polarization studies of individual lines (or a piece of continuum) and has maximum sensitivity when pointed to a specific solar feature.

A typical operational scheme for X-ray studies might work as follows. A simple photometer signals the onset of an energetic solar event (a signal from ground-based observers could do the same). Two grid-collimator photometers, one for each axis of the pointing mechanism, begin a line scan of the sun and "peak-seek" onto the most intense feature (say in a 1 - 8 \AA band). The telescope-spectrometer systems are slaved to go to the same region sought out by the collimated photometers, or else the whole complement of instruments is taken there by the pointing mechanism. Finally a set of spectroheliograms and/or spectrograms and polarization measurements is initiated.

Hard X-Rays, Gamma-Rays, and Neutrons

The objective is to acquire a comprehensive set of measurements on the characteristics of hard X-ray, gamma-ray and neutron emission from the flaring and non-flaring Sun in order to obtain insight into the triggering mechanism of a solar flare, the total energy content of a flare (in conjunction with other measurements), and into the acceleration, containment, and release of charged particles during the flare. The characteristics in the photon spectral range of 0.001 to 100 MeV that must be measured to achieve this objective are:

1. Spectral energy distribution for X-ray and γ -ray for continuum and line emission.
2. Temporal history of the X-ray and prompt γ -ray emission with a time resolution of better than one second.
3. Polarization of the X-ray emission.
4. Location of the X-ray emission in the solar atmosphere as a function of time and energy (this may be possible only for limb flares).
5. Flux, spectrum, and temporal dependence of neutron emission.

The very low flux values likely to be encountered require detection with large collecting area for solar neutrons and γ -rays. This is particularly true for the highest energy γ -rays from π^0 decay, which relate directly to the highest energy particles associated with flares. Typical fluxes are likely to be in the region $10^{-4} - 10^{-5} \text{ cm}^{-2} \text{ sec}^{-1}$ for neutrons, and the π^0 γ -rays will require detection areas on the order of a few M^2 .

Likely detectors are multiplate spark chambers for the high energy γ -rays, scintillation counters for neutrons and medium energy γ -rays, and modulation collimators with proportional counters for hard X-rays.

SPECIFIC INSTRUMENTS AND TECHNOLOGY

The further development of instrument assemblies must be pursued. Some candidate instruments are listed:

- Magnetographs: for use in the visible, UV and XUV region. An instrument has been described for use in the visible and near IR, serving as a magnetograph and Dopplergraph, which would have a field of view of 3×3 arc minutes and optimum spatial resolution of 0.2 arc sec, simultaneously measuring the intensities in the blue and red wings of a given spectral line in two degrees of circular polarization.
- Visible and near infrared Stokes meter: would measure all four Stokes parameters simultaneously with very small (2×2 arc sec) field of view.
- Photoheliographs: aperture 65 - 150 centimeters
- Coronagraphs
- High spectral resolution (0.01Å or better) spectrometers in the XUV spectral region.
- High spectral resolution (0.001Å) collimated crystal spectrometers.
- High spectral resolution (0.01Å) normal incidence stigmatic spectrometers from 1000Å to the visible.
- Automated (closed loop, computer controlled) flare sensor.

It is recognized that single components and component combinations (instruments) must be complemented by additional systems technology development for achieving the goals of space oriented observational solar physics. Instruments and instrument assemblies alike have common features influencing performance. Some areas of instrumental design and space flight interfaces which require attention are:

- Maintenance of surfaces of coronagraphs, grazing incidence telescopes, grazing incidence collectors, crystals, etc., free of dust and other contaminants.
- The use of modular replacement — resupply designs for components (i.e. - open window detectors) and instruments (i.e. - spectrometers aft of high resolution telescopes).
- The development of compact instrumental co-alignment (1 arc sec) hardware such as sensing images reflected from slit jaws.
- Economical thermal/mechanical design concepts and material selection which minimize sensitivity of high resolution instruments (i.e. - spectrometers) to thermal gradients, changes in thermal gradients, and material microcreep.
- Development of effective means to eliminate electromagnetic interference between Shuttle and experiments. This includes the development of standard power supplies for use with instrumentation of many disciplines, avoiding ground loops through conductive decoupling except for single point grounding.

Individual components that require development include:

- Narrow band multilayer (3Å) filters for the visible and ultraviolet spectral region.
- Narrow band phase filters for use in the XUV and UV spectral region.
- Medium narrow band (20Å) multilayer prefilters in the ultraviolet and visible region.
- XUV magnetograph polarizing/analyzing components.

- Low scatter surfaces for glancing incidence imaging optics.
- Alternate X-ray imaging techniques to achieve high throughput and spatial resolution (Dicke, Baez, Wolter, and Fresnel cameras).
- Low scatter, efficient diffraction gratings which can be used at fast focal ratios.
- Crystals which can be used to resolve line profiles (1 to 20 Å spectral region).
- Collimators (~5 arc seconds) for crystal spectrometers.
- High emissivity, low absorption coatings for photoheliograph mirrors.
- Large (up to 1.5 meter diameter) precision ($\lambda/50$ to $\lambda/60$ rms) mirrors for photoheliograph type telescopes.
- Matrix detector arrays.

PLATFORMS

SOUNDING ROCKET, AIRCRAFT, AND BALLOON CLASS

The Space Shuttle offers the exciting potential for extending the very successful sounding rocket, balloon, and aircraft experiment approaches in solar physics, maintaining their advantages and overcoming their limits on observing time, weight, and altitude. These approaches have historically provided a rewarding avenue in space science research. They have been, and continue to be, the work-horses of discovery for many disciplines, including solar physics. Among their advantages are:

- Short time from experiment concept to flight
- Rapid turnaround after refurbishment or modification
- Recovery of photographic data
- Pointing systems available with stability to a few arc sec
- Relatively low cost

It will be possible with the Shuttle to extend these types of investigations with observing time and/or weight increases by orders of magnitude.

Instruments in this class will continue to be developed during the pre-Shuttle period. Designs of these should be worked out with a view toward eventual flight on the Shuttle, so that they will be ready for the early Shuttle flights where a minimum of complication will be desirable. Reasonable adaptations will make these payloads flight-qualified for the Shuttle. A number of them can be taken up simultaneously, thus permitting investigations with independent but correlated instruments, as well as substitution of one modularized payload unit without changing the others. It will be possible to use common pointing controls and supporting instrumentation for many different payload units in this class.

Shuttle Sortie planning should include provisions for this class of payload units operating in airlocks, on the pallet, and free-flying. Some adaptation of existing pointing mechanisms may be required to make these payloads compatible with the various operating modes from the Shuttle.

This approach to Shuttle Sortie use will respond affirmatively to the continued urging of the scientific community and advisory groups for substantial increases in the sounding rocket, aircraft, and balloon program areas. Additionally it will provide a mode where individual scientists can continue to make contributions while large scale dedicated and problem-oriented missions are underway.

SEMI-AUTOMATED POINTING PLATFORM

A semi-automated Pointing Platform based on an evolution of the OSO series is needed for the Shuttle era. During the decade of the 1960's the OSO spacecraft series represented the pioneering effort, beyond sounding rockets and balloons, for solar physics. The presently evolved OSO series (I, J, K) far exceeds the capabilities of earlier OSO's and represents the logical next step in solar studies. In the Shuttle era this type of instrument platform should further evolve to take advantage of the instrument up-date, module replacement, retrieval, and other capabilities to be introduced by the Shuttle. This observatory class will continue to free-fly because observations for periods of months are required, and this is well in excess of single Sortie flight durations. The evolution of Shuttle platforms in this class may take advantage of OSO, ATM, and OAO technology with considerable cost-effect benefit.

Some specific areas where improvement will be needed include:

- Provision for more power and higher data rates
- Increased real time operation capability
- Addition of an on-board central computer to accommodate replacement of entire experiment modules as research objectives advance

LARGE PLATFORMS

Large Finely Pointed Platform

The telescope and instrument systems that will be doing solar physics in the Shuttle era will ultimately require image stability of the order of 0.01 arc seconds and accuracy of about 1 arc second. The pointing stability should be kept as steady as possible in order to minimize the need for image motion compensation in the individual experiment packages. A pointing control to fulfill these requirements would have to be a three axis control capable of guiding a 1,500 kg payload. Additionally, the system should be capable of slewing a distance of several solar diameters in a period of minutes with a settling time of ten seconds at the new pointing coordinates. The pointing control should be capable of being driven manually (joy stick) or by computer control.

The requirement of up to 0.01 arc seconds image stability is admittedly severe. It would seem prudent and acceptable to develop a pointing control in steps, i.e., initial flights with 0.1 arc second stability, followed by later flights of greater stability culminating in a 0.01 arc second system. Note that image stability rather than pointing stability is required and is attainable by image motion compensation within the instruments. This is costly and makes instruments more complex than would be desirable. A trade-off must be made between platform stability and image motion which will require a continuing dialogue between scientists and Shuttle and Sortie module designers.

Large Coarsely Pointed Platform

Large, coarsely pointed platforms will permit doing solar physics with instruments which observe solar flares with high time resolution without regard to their location on the disk, and for those experiments which contain their own fine pointing controls (one should not move the whole Shuttle to bring a fine pointing control within range of lock-up). Some experiments will be amenable to coarse pointing from the Shuttle itself.

When attached to the Shuttle such a platform should be capable of operating in an altitude-azimuth solar tracking mode within the constraints (unknown at this time) imposed by Shuttle maneuvers. The platform should be able to point a 3000 kg payload to within one to two degrees or less of the sun and maintain this pointing for each orbit sunrise-sunset cycle.

An alternative to a coarse pointing facility on the Shuttle is to permit experimenters to fly their own coarse pointing controls. Such controls have been developed for balloon flights by several groups (although the balloon environment does not have the same hard vacuum, thermal, and mechanical shock conditions as the Shuttle). Tests on current balloon pointing controls would indicate the design changes necessary to produce a system compatible with the Shuttle. New balloon pointing systems will be designed and built and flown between now and the first Shuttle flights. It would seem wise to design and test these systems with Shuttle use as a possible application.

Interdisciplinary Platforms

All four platforms could be interdisciplinary. The sounding rocket and semi-automated platforms are likely to be primarily solar and to be applicable to other disciplines. The two large platforms may be developed as interdisciplinary.

Large Platform Requirements

The following paragraphs state recommended design objectives. Platforms as defined in this discussion include free-flying stabilized instrument mounting bases, as well as bases which remain attached to the Space Shuttle.

The problem-oriented approach to solar physics observations, which is recommended elsewhere in this report, dictates that future space platforms must be capable of:

- Mounting and permitting concurrent operations of multiple instrumentation
- Permitting instrument operation by the on-board crew or by ground crew
- Transmitting solar images by video downlink
- Offset pointing anywhere on the sun
- Permitting in-orbit substitution of subsystems

- Being recovered, refurbished and relaunched by the Shuttle
- Transmitting high data rates up to 10^7 bps for short periods

THE ROLE OF MAN

DISCUSSION

In this report several modes of experiment control are emphasized, ranging from the Sortie configuration to free-flying adjunct satellites. In this section, we note some particular considerations of the role of man, emphasizing the Sortie mode, but noting also the crucial role of man in the free-flying adjunct satellite mode. Tight interaction between the control center and the orbiting instrument package, heretofore impossible due to inadequate data transmission from ground to orbit and back, will allow complex pointing maneuvers, coalignments, response to transient events, and quick-look analysis to be performed by teams of scientists. In this manner, substantial improvements in the efficiency of observing time employing the satellite may be realized.

THE ROLE OF MAN IN SPACE SCIENCE IN THE SHUTTLE ERA

In an orbiting observatory, man can generally contribute in three ways: as an observer, an instrument operator, and a technician.

An important and challenging aspect of solar space observations is the opportunity for man to significantly increase the selectivity (and hence, in many cases the scientific worth) of the data by using his judgement. This opportunity stems from the fact that, as the spatial resolution and field of view of solar instruments become increasingly smaller, the necessity of such selectivity increases. Decisions must be made on where to point, what instrument modes to use, and when to acquire data. Many of these decisions are best made on the ground after careful analysis of the solar data, instrument status, etc. Some decisions could be made before launch and incorporated into automated modes; however, a good number of them are best made by an observer on the satellite, monitoring the unpredicted variations of solar features in space, time, and wavelength. If the ground had all the on-board controls and displays continuously available, and if the instruments were fully equipped for remote control operation, there would be no need for an on-board solar observer. However, the present coverage of the tracking and data network for low earth orbit provides less than continuous coverage. Also, bandwidths available for data transmission limit the

quantities of data and of commands that can be transmitted. A full range of instrument displays is necessary. This could include a realtime video magnetograph and monitors for selectable XUV and UV lines, several X-ray spectral regions, tunable ($H\alpha$ and Ca K) filters for disk and limb features, and white light disk and coronal displays. Continuous transmission of data and commands for selected time periods and the automation of instrument controls for remote operation would be required. It could be more costly in complexity, weight, and money than the addition of one or even several crew members to a Shuttle orbiter crew.

The observer should have picture storage capability that permits comparison between the realtime sun and its recent history, thus enabling him to pinpoint centers of special activity and interest. These displays must be available so as to allow a rapid determination of the nature of transient events on the sun. Indeed, the appropriate response to such transient events can be a major contribution of the crewmen to the observation program.

Following decisions on the type of data to acquire, a variety of operations must be performed. Each operation in itself is a straightforward and simple task, but collectively the total operations may become complex. Although some operations could employ automated modes, controlled by computer from the ground, high flexibility, performance, and efficiency in observing programs can be achieved by manual mode of operation.

At the moment it would be difficult to say which of the three uses of man - observer, operator, and technician - will be the most important. If only one crewman can be accommodated, he should represent all three capabilities. Many astronomers are excellent technicians and it will not be difficult to find an orbiting astronomer who is his own best technician and operator. If two crewmen can fly, at least one should be a scientist, and the other may be a technician.

Instruments and systems should be built in such a way that certain services, repairs, or replacements in flight can be achieved, without unduly complicating designs. The possibility of retracting or retrieving components into the pressurized Sortie Lab for servicing or repairing should be investigated.

Some specific tasks of the crewmen include assistance in the initial deployment, assembly and setup of the observatory, operations including removing launch locks from sensitive moving elements, relative coalignment of instruments, calibration, focusing, and system tests. Once the observatory is in operation, the crewmen would be available for standard maintenance and servicing, instrument recalibrations, coalignments, focusing, and film change, in addition to their main task of assuring an efficient program of observations.

CAPABILITIES REQUIRED OF THE OBSERVER, OPERATOR AND TECHNICIAN

The position of observer should be filled by a person having a firm background in solar physics, including either formal solar physics training or training in a related science and subsequent application to solar physics. By flight, the solar observer should also be trained as a competent instrument operator and hence would be regarded as a Flight Scientist. In his function as a technician, he should have an in-depth knowledge of the physical details of each instrument, a knowledge which is quite distinct and is obtained in a different manner than the more fundamental and operational knowledge needed for the function of the Flight Scientist. He should have a demonstrated capability in working with the complex equipment and instrumentation. Training should make him well skilled in the areas of assembly, setup, maintenance, component replacement, and instrument diagnostics and repair.

As mentioned above, the functions of Flight Scientist and of Flight Technician could be combined in one person, or they could be vested in two different crewmembers. The choice will depend on the nature and the complexity of the equipment onboard the Shuttle Orbiter.

DATA MANAGEMENT

The data requirements for Shuttle supported solar physics will be considerably greater than those of the automated solar spacecraft of the 70's. For example, the high resolution instruments will include imaging devices able to display high resolution images of the sun at one or more wavelengths which span the range from the infrared to the hard X-ray region. Since significant solar phenomena are now known to occur on a time scale of one second or less, the problem is compounded by the need to encode a large number of high resolution images in a short period of time.

Additional difficulty arises from the need to evaluate some of these images in real time or near real time. This will often require rapid changes in instrument level setting and/or mode of operation, as well as quick pointing capability to specific areas on the sun in response to the changing conditions found there. The near real time evaluation of the solar images may be done by a payload specialist visually inspecting an electronic TV or photographic display unit, or by an onboard computer loaded with an image evaluation program, or by image transmission to the ground. It is also possible that a combination of all three techniques may be used at times.

A TV link-up between the ground and the Shuttle may be considered as part of the general communication system between ground-based solar physicists and the

payload specialist for identification of areas of particular interest and loading of the image evaluation program.

In order to conduct real time observations and manage the very large quantity of data collected by a solar imaging device on the Shuttle or its subsatellites, we recommend that the following facilities be provided as part of the Shuttle data management and communication system:

- Data relay spacecraft system providing both continuous real time T.V. transmission and, part of the time, a 10^7 bits per second data transfer rate from the Shuttle or its subsatellites to the ground and conversely. A few ground based solar observatories should be selected and equipped with visualization equipment for correlation with this space data.
- Onboard computing facilities for information storage and cataloging, providing easy access to stored data to expedite Sun evolution predictions and decision making. Computing facilities may also be used for management of several instruments simultaneously onboard the Shuttle or its subsatellites.
- Onboard magnetic tapes for post flight data analysis. This analysis will require the entire fund of data collected by the solar payload.
- Onboard film storage and handling, which may imply the need for a film developing facility aboard the Shuttle. At least dry processing film techniques of the Polaroid type may be considered for checks of instrumental performances, focusing and fine adjustment.
- Down and up continuous and extensive voice communication link is essential for good coordination between solar physicists on the ground and the payload specialist.
- Film recovery capability from the Shuttle subsatellite.

Any reduction in the data rate will probably increase the cost and complexity of the payload, which will have to be provided with greater capability for preliminary analysis and storage of data. This will be most critical for the free-flying payloads. Payloads attached to the Shuttle Orbiter will naturally use the on-board tape recorders, which are adequate as baselined.

The non-image forming solar experiments will use, as a minimum requirement, a pcm data system of greater capacity than that used on OSO-I. The system should have a bit rate of at least 12,800 bps, a capacity for 1024 stored and/or

real time discrete commands, a tape recorder system capable of storing at least two complete orbits of data at the above rate, and a computer capable of reformating the telemetry both from a single experiment and also from the entire complement of experiments. The computer should also be capable of determining appropriate operating modes for the experiment, using programs which can be revised from the ground.

FLIGHT SCHEDULE

The Summary Flight Schedule given in Table 8 gives a solar program through 1990. Some sounding rockets remain in the program in the 1980's for eclipses, flares, and in-orbit instrument calibrations. The solar maximum mission spacecraft may be used as a semi-automated platform in the Shuttle era. Space labs are used simultaneously for research and for LSO instrumental development. The four ways to use the Shuttle are described in summary form in the Appendices, following the standard format, as requested. Table 8 refers to the four Appendices with appropriate parenthetical references.

Table 8

**Outline of the Proposed Total Flight Schedule of Space Lab and Non-Space Lab
Missions Needed to Meet the Discipline Goals and Objectives**

| | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Dedicated |
|---|----|----|-----|----|-----|----|----|----|----|----|----|----|----|----|----|----|----|-----------|
| Sounding Rockets | 20 | 20 | 20 | 20 | 20 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | - |
| Balloon | 2 | 2 | 2 | 3 | 4 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - |
| Shuttle - Sounding Rocket Mode (C) | | | | | | 10 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | No* |
| OSO** | I | | (J) | | (K) | | | | | | | | | | | | | - |
| Solar Max | | | | | 1 | | | | | | | | | | | | | - |
| Shuttle - Semi- automated Platform (A) | | | | | | | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | No |
| Shuttle - Space Lab (B) | | | | | | 1 | 2 | 2 | 2 | 2 | 2 | | 2 | 2 | 2 | 2 | | Yes |
| Shuttle - LSO (D) | | | | | | | | | | | | 1 | | | | | 1 | Yes |

*Number of rocket or balloon class payload opportunities. Several or all may be accommodated on a single non-dedicated mission in any one year.

**It is hoped that the Recommendation that OSO's J and K can be flown will be carried out, but not firm plans exist at this date.

APPENDIX A

DEPLOYMENT AND/OR SERVICE OF A SEMI-AUTOMATED SOLAR PLATFORM

REASONS THE SORTIE MODE WOULD BE PREFERRED OVER OTHER METHODS FOR EACH OF THE POTENTIAL CONTRIBUTIONS OF THIS TYPE SORTIE MISSION:

- New instrumentation can be substituted in the spacecraft to attack specific solar physics problems. No need to build a new spacecraft every time, very low cost compared to new launch
- Instrumentation can be returned, updated, and flown again at little more than the cost of rocket instrument refurbishments
- Spacecraft consumables, components, can be replenished, repaired, updated
- High data rates during solar transients
- Astronaut can operate the free-flying platform, do fine guiding, react to targets of opportunity
- Shuttle can serve as a ground-station, operation optional from the ground

REQUIREMENTS THIS TYPE MISSION PLACES ON THE SHUTTLE IF THE POTENTIAL CONTRIBUTIONS ARE TO BE REALIZED:

- Length of Flights — Time required to update, repair spacecraft, exchange experiments, is of the order of a few days. With operation optional from the shuttle or from the ground, the astronaut can operate it usefully for whatever time is available. Time between Shuttle visits to the platform: three months minimum or more.
- Orbit — To be optimized for observational program
- Data Requirements — To be at least 6,400 bps. Command capability, including stored command, is important.

- Role and Number of Personnel in Orbit — At least two persons, one a payload specialist, for substitution of experiments, repair of platform and replenishment of supplies. If operation from the Shuttle, need a specialist trained in programming spacecraft computer.
- Stabilization and Pointing — Provided by platform.
- Power and Thermal — Provided by platform.
- Weight and Volume — Spacecraft weight 1,000 kg, volume 8 m³.
- EVA Requirements — Retrieve spacecraft. Delicate operation.
- Correlative Measurements — Ground-based measurements, calibration sounding rocket, Shuttle platforms desirable (see other Appendices)
- General Support Equipment — Computer, data handling and storage facilities, means to perform above mentioned operations on the spacecraft. Capture and deployment device.
- Documentation Requirements — Document any problems in installation, servicing of instruments, spacecraft. Record all commands and programming of spacecraft computer.
- Special Operating Constraints — Minimum production of effluents of any kind from the Shuttle while spacecraft may be exposed to them.
- Contamination Requirements — Maximum freedom from contamination by harmful effluents in the form of gas, vapors, and particles, at all times during handling of the spacecraft or while it is near the Shuttle.

POLICIES AND PROCEDURES

Policies and procedures which must be changed or instituted to fully exploit the Shuttle Sortie mode and reduce the cost of research in space are:

- Reduce Quality Assurance requirements.
- Handle instrumentation as for a scientific sounding rocket flight.
- The responsibility for making the instrument work rests with the scientist, he has the most to gain and lose anyhow. Don't attempt to control his procedures except if required for safety reasons (no explosives, etc.)
- Subsystems should be easily replaceable.

BRIEF DESCRIPTION OF ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

User community is estimated to include 80% of the solar physics community, in the U. S. A. and 50% abroad. This amounts to about 100 institutions with some 500 or more individual scientists, not counting engineers and observers.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

Advertise the opportunity to provide instrumentation to replace that on the solar maximum mission, select two to five instruments, half pointed section sized, depending upon quality of proposals. Provide a fixed amount of money, initially negotiated, to the scientist and tell him to produce the best instrument he can for that amount of money. The best completed instruments that make a problem-oriented payload fly first. The scientist gets a portion, here about 40% of the observing time. The balance goes to guest investigators.

RECOMMENDATIONS ON FUTURE ACTIONS REQUIRED TO IMPLEMENT THE SORTIE MISSION INCLUDING SRT, STUDIES AND FUTURE PLANNING ACTIVITIES

1. The Goddard Space Flight Center should study alternatives for a Solar Maximum Mission for later Shuttle use as the Semi-Automated Solar Platform.
2. Build in maintainability and the capability to exchange instrumentation and parts. The additional costs should be compensated for by relaxation of quality assurance on the spacecraft and instrumentation in view of the planned Shuttle visits to the spacecraft.

APPENDIX B

DEDICATED SOLAR SPACE LAB FLIGHT

REASONS THE SORTIE MODE WOULD BE PREFERRED OVER OTHER METHODS:

Sortie mode is preferred because of the large load capability, sufficient time to test out instrumentation and return sample data, realistically simulate LSO operation, and return of the instrumentation to the ground for improvements. It is possible to address those solar physics problems which can be attacked with observing time of the order of days.

REQUIREMENTS THIS TYPE MISSION PLACES ON THE SHUTTLE IF THE POTENTIAL CONTRIBUTIONS ARE TO BE REALIZED

- Length of Flights — One week to one month.
- Orbit — Optimized for observational program.
- Data Requirements — Photographic and digital data handling. Large transient loads, data compression some of the time. Note especially photoheliograph rate in first payload.
- Role and Number of Personnel in Orbit — Spans the whole spectrum of astronaut activities (See ROLE OF MAN):
- Stabilization and Pointing — See PLATFORMS.
- Power and Thermal — Thermal: continuous sun viewing in fully sunlit orbit, otherwise intermittent nights with consequent transients. Power: several kilowatts peak. Average lower, trade-off power versus instrumentation cost and complexity.
- Weight and Volume — For one instrument, see appropriate tables. For entire payload, estimated 9000 kg and one Shuttle payload compartment.
- EVA Requirements — None in short flights, except if unexpected repairs become necessary.
- Correlative measurements — See GROUND BASED ACTIVITIES.

- General Support Equipment — Pointing platform, data link, power, command, video, control console, data storage.
- Documentation Requirements — Minimum. Record all operations of the instrument controls, time, orbital parameters, problems.
- Special Operating Constraints — Minimum effluents from Shuttle while instrumentation is exposed.
- Contamination Requirements — Minimum effluents such as gas, vapor, or particles from Shuttle while instrumentation is exposed.

POLICIES AND PROCEDURES

Policies and procedures which must be changed or instituted to fully exploit the Shuttle Sortie mode and reduce the cost of research in space:

Same as Appendix A.

BRIEF DESCRIPTION OF ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

Same as Appendix A assuming several flights.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

Select Principal scientist. He should have rights to about 40% of the observing time. Balance to guest investigators.

RECOMMENDATIONS ON FUTURE ACTIONS REQUIRED TO IMPLEMENT THE SORTIE MISSION INCLUDING SRT, STUDIES, AND FUTURE PLANNING ACTIVITIES

1. Develop instrumentation as prototypes of LSO instruments, full scale or scaled down, fly on sounding rockets and balloons in preparation for first orbital tests on Shuttle.

2. Development of a solar telescope for high spatial resolution work will continue (65 cm aperture). Begin development of complementary spectrograph. High resolution UV, XUV, X-ray, and IR instrumentation to be developed for the same flight.
3. High energy telescopes and spectrometers development to be initiated.
4. Develop interdisciplinary fine pointing platform, feed back stability and pointing accuracy, and other specifications so that trade-off with image motion compensation can be made.

APPENDIX C

SHUTTLE SOUNDING ROCKET/BALLOON PLATFORM FLIGHT

REASONS THE SORTIE MODE WOULD BE PREFERRED OVER OTHER METHODS:

- Gives additional time, by factors 10 to 100 at least, over sounding rockets flights.
- Maintains, in principle, all advantages of sounding rocket/balloon operation such as ease of access, rapid turnaround, no documentation of quality assurance, ability to fly exploratory instrumentation, train students, etc.
- If several solar sounding rocket payloads are carried in one flight it becomes possible to use some of them simultaneously for problem oriented studies, or sequentially for evolutionary studies.
- Instruments will be available from sounding rockets and balloons.

REQUIREMENTS THIS TYPE MISSION PLACES ON THE SHUTTLE IF THE POTENTIAL CONTRIBUTIONS ARE TO BE REALIZED

- Length of Flights — One orbit to several days.
- Orbit — No constraints, except altitude minimum depending upon payload.
- Data Requirements — Limited telemetry, photographic film.
- Role and Number of Personnel in Orbit — Depends upon whether free-flying or attached. One person should suffice. He would make final adjustments, if any, to instruments, load, and retrieve film, monitor performance, select modes in some cases, retrieve instruments, possibly prepare for second sequence of observations.
- Stabilization and Pointing — Shuttle as stable as possible as base for pointing platform if attached, no constraints if free-flying.
- Power and Thermal — Power internal or Shuttle, nominal. Payloads not normally built to take large thermal loads.

- Weight and Volume — Each sounding rocket class payload. Weight 250 kg, volume 0.5 m³. Balloons about 10 - 100 times more.
- EVA Requirements — None.
- Correlative Measurements — See Appendix A.
- General Support Equipment — Standard small pointing platform. See Appendix B. Capture and deployment device if free flyer.
- Documentation Requirements - Minimum.
- Special Operating Constraints - Shuttle stable if attached, minimum effluents (Part A).
- Contamination Requirements — Protect payload from effluents, such as vapor, gas, or particles (A I).
- Other — Would like to be able to carry up to six payloads or more in one Sortie, but can utilize even a single payload. In that case one would want flights more often, but would lose simultaneity of observations. A total of 20 sounding rocket class payloads in solar physics are needed per year, 15 of them on the Shuttle. Three flights of five payloads each were assumed in Table 8.

POLICIES AND PROCEDURES

Policies and procedures which must be changed or instituted to fully exploit the Shuttle Sortie mode and reduce the cost of research in space: It is mandatory that it be possible to fly a sounding rocket payload without further qualification requirements if the payload has successfully flown before, or has undergone the normal sounding rocket pre-flight testing and preparation. In that case, the cost for payloads is down to refurbishment plus any changes.

BRIEF DESCRIPTION OF ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

About 15 to 25 research groups in this country, with 100 or more individual scientists. Somewhat fewer abroad. This is the opportunity for new groups, the number of which is unpredictable.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

Same as in present Sounding Rockets Program.

RECOMMENDATIONS ON FUTURE ACTIONS REQUIRED TO IMPLEMENT THE SORTIE MISSION INCLUDING SRT, STUDIES, AND FUTURE PLANNING ACTIVITIES

1. Initiate studies on how existing pointing controls (SPARCS) can be used to support sounding rocket class payloads for periods of at least one hour between servicing. Identify any changes that may be needed.
2. Survey the scientific community to establish candidate payloads that can profit from extended observations periods. Identify candidates.
3. Determine if free-flying or attached modes are preferred.
4. Provide verification flight as piggyback on a larger mission of any kind, in the preferred (free-flying or attached) mode.

APPENDIX D

LARGE SOLAR OBSERVATORY

REASONS THE SORTIE MODE WOULD BE PREFERRED OVER OTHER METHODS:

Sortie is not preferred over a free-flying platform, but may be used for verification flights for the entire observatory as well as for individual instruments.

REQUIREMENTS THIS TYPE MISSION PLACES ON THE SHUTTLE IF THE POTENTIAL CONTRIBUTIONS ARE TO BE REALIZED

- Length of Flights — Indefinite.
- Orbit — Optimized for observational program.
- Data Requirements — High. Trade-off data rate versus continuity of operation.
- Role and Number of Personnel in Orbit — Several observers (payload specialists) could be usefully employed.
- Stabilization and Pointing — Stabilization to 0.01 arc second needed for images. Can be traded between platform stabilization and image motion compensation internal to instruments. Pointing accuracy of 0.1 arc second required. Can be attained by slit-jaw displays and joy stick capability in the instrumentation.
- Power and Thermal — Power requirements large, including for thermal control. Can be traded against instrumentation sophistication.
- Weight and Volume — Weight and volume depend upon instrumentation used.
- EVA Requirements — To be determined.
- Correlative Measurements — Ground-based, free-flying semi-automated platform.
- General Support Equipment — To be determined, includes computer, data storage, film processing.

- Documentation Requirements — Minimum recommended. See Appendix B.
- Special Operating Constraints — Minimum effluents while instrumentation is exposed.
- Contamination Requirements — Minimum effluents of gas, vapor, particles.

POLICIES AND PROCEDURES

Policies and procedures which must be changed or instituted to fully exploit the Shuttle Sortie mode and reduce the cost of research in space.

See Appendix A.

BRIEF DESCRIPTION OF ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

Probably even larger than described in Appendix A.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

Instrumentation must be developed under direction of principal scientists, one for each major piece. In return, he gets a percentage of the observing time, to be determined at 10 to 40%. Balance to guest investigators. Central ground-based facility for interfacing users with LSO data, ground-based data, theorists, scientists from other disciplines, is desired. Preferred at Kitt Peak, Sacramento Peak or another major ground-based observatory.

RECOMMENDATIONS ON FUTURE ACTIONS REQUIRED TO IMPLEMENT THE SORTIE MISSION INCLUDING SRT, STUDIES, AND FUTURE PLANNING ACTIVITIES:

1. Instrumentation needs development in the laboratory now.
2. Prototype flights on sounding rockets, balloons, and the early Sortie Missions.
3. Full scale verification flights on the Sortie (see Appendix B).

The following are the contents of each volume of this series:

EXECUTIVE SUMMARIES

VOLUME 1 — ASTRONOMY

VOLUME 2 — ATMOSPHERIC AND SPACE PHYSICS

VOLUME 3 — HIGH ENERGY ASTROPHYSICS

VOLUME 4 — LIFE SCIENCES

VOLUME 5 — SOLAR PHYSICS

VOLUME 6 — COMMUNICATIONS AND NAVIGATION

VOLUME 7 — EARTH OBSERVATIONS

VOLUME 8 — EARTH AND OCEAN PHYSICS

VOLUME 9 — MATERIALS PROCESSING AND SPACE MANUFACTURING

VOLUME 10 — SPACE TECHNOLOGY